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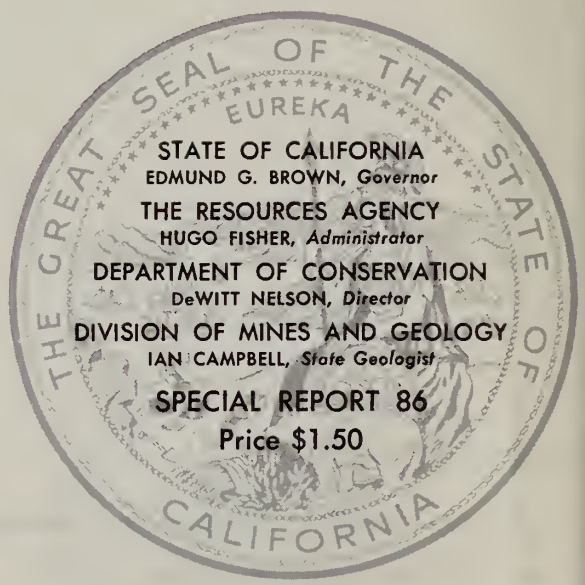
Special Report 86

California Division of Mines and Geology

Ferry Building, San Francisco, 1965

Special Report 86 is the second in the series *Short Contributions to California Geology*. The first, Special Report 82, was published in 1963.



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GEOLOGY OF THE CENTRAL PART OF THE RAMONA PEGMATITE DISTRICT SAN DIEGO COUNTY, CALIFORNIA*

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ABSTRACT

The Ramona pegmatites of central San Diego County, California, occur as stringers and dikes in tonalites of the Cretaceous southern California batholith. In the district, which covers about one-half a square mile, the pegmatites form a pattern of subparallel anastomosing dikes with a general northwest strike and a southwestward dip of about 45 degrees. The dikes appear to have been emplaced along a well-developed set of fractures. These fractures are not parallel to other planar structural features, and they transect a contact between plutons of different composition.

Most of the dikes consist of fine- to medium-grained aggregates of microcline-perthite and quartz, with scattered tourmaline, garnet, and muscovite. Some of the dikes are asymmetrically zoned. In these, the basal zone, constituting about one-third to one-half of the dike, is a soda-rich aplite ("line rock") with garnet-tourmaline rich layers subparallel to the footwall of the dike. The uppermost zone of these dikes is graphic granite; typical inner zones consist of quartz-perthite pegmatite, albite-quartz pegmatite, and "pocket pegmatite". Corrosion and secondary mineralization followed crystallization of the pegmatites.

INTRODUCTION

Nature of investigation. The Ramona pegmatites, in central San Diego County California, have been known since 1903 for their yield of tourmaline, topaz, garnet, beryl, and smoky quartz, and hence have received considerable attention from mineralogists. The present investigation has been primarily petrologic. It included detailed field studies of the approximately half a square mile area that comprises the pegmatite district, supplemented by petrographic and mineralogical work in the laboratory. About 25 days between March 1957 and February 1960 were spent mapping the central part of the district (figure 2), making detailed cross sections of dikes (figure 3), and mapping two of the principal mines of the district (figures 4 and 5). Microscopic examinations were made of 186 thin sections and 85 samples of crushed minerals in order to determine mineralogical compositions and paragenetic relationships. All modal analyses were made on thin sections that had been stained with sodium cobaltinitrite to permit accurate discrimination of potassium feldspar from other rock constituents.

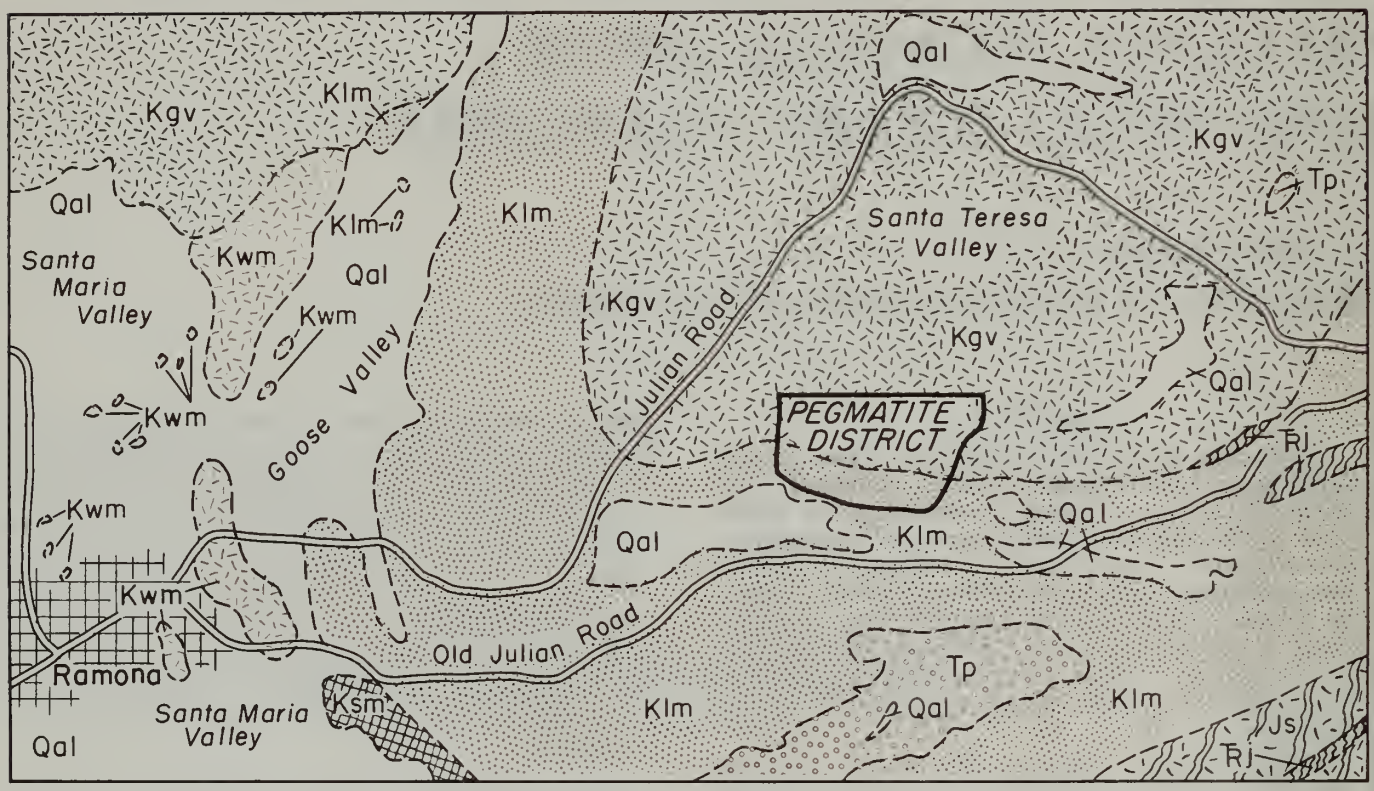
Acknowledgements. This investigation was started at the suggestion of Dr. R. H. Jahns of the Pennsylvania State University; his continued interest and suggestions are greatly appreciated. Mr. F. Harold Weber, Jr. of the California Division of Mines and Geology, critically reviewed the manuscript.

A research assistantship, the Harvey Mudd Summer Fellowship, and use of the laboratory facilities under the aegis of the California Institute of Technology, helped make this study possible. Permission to use the thin section and photographic laboratories of Mr. Rudolph von Huene is appreciated.

The property owners within the Ramona district have been cooperative in many ways. In this connection, particular thanks for many personal kindnesses are due Mr. and the late Mrs. L. B. Spaulding of Ramona.

Previous investigations. In an early report of the State Mineralogist, Fairbanks (1893) mentioned that pegmatite dikes near Ramona contained tourmaline, garnet, and muscovite but made no note of the occurrence of gem-quality minerals. Gem-quality minerals evidently were first recognized in the Ramona

* Based on a Doctor of Philosophy dissertation presented to the Geology Division, California Institute of Technology, in 1960. Submitted for publication August, 1961.



EXPLANATION

Qal — Alluvium

Tp — Poway(?) Conglomerate

Kwm — Woodson Mountain Granodiorite

Klm — Lakeview Mountain Tonalite

Kgv — Green Valley Tonalite

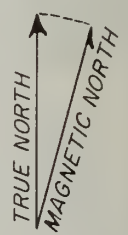
Ksm — San Marcos Gabbro

CRETACEOUS — EOCENE — RECENT

Js — Stonewall Granodiorite

Rj — Julian Schist

TRIASSIC(?) JURASSIC(?) (pre-batholithic)



Geology after Richard Merriam (1954) modified by Dale R. Simpson.
Culture from the Ramona 15' quadrangle, U.S. Geol. Sur.

pegmatites in 1903, and the first report of the deposits was published two years later by Kunz (1905).

Between 1903 and 1924, W. T. Schaller (1910, 1927) studied the mineralogy and geological relationships of asymmetrically zoned pegmatites in southern California. Sinkankas (1957) described the geologic setting of the pegmatites and the mineral discoveries recently made in several of them.

Several more general papers are in the bibliography: Miller (1935), Larsen (1948), Merriam (1941, 1946, and 1954), and Jahns (1954b). Descriptions of the mines appear in reports by Tucker (1925), Tucker and Reed (1939) and Weber (1963). The location of pegmatite districts in southern California is shown by Jahns and Wright (1951, p. 7).

GEOLOGIC SETTING

The Ramona region is underlain by intrusive rocks of the large and complex Cretaceous southern California batholith of the Peninsular Ranges province. This batholith comprises many separate intrusive units, as shown by Larsen (1948) and Merriam (1946, 1954). Three of the units—Green Valley Tonalite, Lakeview Mountain Tonalite, and Woodson Mountain Granodiorite—form the country rock of the Ramona pegmatite district; in addition, two bodies of pre-batholith metamorphic rocks lie about 1½ miles east of the main group of pegmatites. Granitic pegmatite occurs as a belt of anastomosing dikes which strike northwest, and cut across contacts between intrusive units (figure 2). Sedimentary rocks of Eocene age cap some of the high ridges and hills in the Ramona area.

Prominent structural features in the area of the pegmatites trend northwest. These features include a major set of joints, a small fault exposed southwest of the main group of pegmatites, and the contact between the two tonalite units. No obvious relationship was found between the joint pattern in the country rock and the size and shape of the plutons. Most of the joints are concordant with the pegmatite dikes. Good examples of this joint set are visible on the south bank of Hatfield Creek near Spaulding dike. Apparently the pegmatites were emplaced along joints of this set. The origin of these joints is problematic as they cannot be related to large scale structural features. It may be that these joints were caused by contraction during the cooling of the batholith, as was suggested by Jahns (1954a), for the pegmatite-filled joints of the Pala district.

The trend of the fault southwest of the main group of pegmatites is N. 70° W., and its dip is about 60° SW. Poorly preserved slickensides show left lateral strike-slip movement of this fault. Slickensides on pegmatite indicates that the fault is post-pegmatite.

The contact between the two tonalites is very irregular because of intertonguing, but it trends about N. 70° W. Gneissoid segregations resulted from inclusions of Green Valley Tonalite arranged in a streaked fashion in the Lakeview Mountain Tonalite near the contact between the two plutons. Because the attitude of these gneissic structures is nearly vertical, it seems likely that the contact between the tonalites also is nearly vertical.

Table 1. Nature and Occurrence of Country Rock

Metamorphic Rocks: Quartz-mica schist occurs as isolated masses between and within the plutonic rock units. The outcrop of schist nearest the pegmatites is about 1 mile east of the main group of dikes. This schist has been correlated with the Julian Schist by Merriam (1946).

Igneous Rocks

Green Valley Tonalite: A rather uniform, medium- to coarse-grained rock exposed mainly north of the central part of the pegmatite area. The major minerals of this rock are plagioclase (An_{43-53}), quartz, and biotite. The rock has an over-all bluish-gray color and on fractured surfaces large poikilitic biotite crystals are visible. A mafic facies of the Green Valley Tonalite crops out near the Little Three mine. This rock has a salt-and-pepper texture which is caused by the abundant equally distributed, fine-grained crystals of black hornblende and pale brown-stained plagioclase.

Lakeview Mountain Tonalite: A medium- to coarse-grained rock that crops out in the southern part of the area mapped. The rock is nearly white, with the major minerals being plagioclase (An_{37-40}), quartz, and biotite. Microcline is present in some specimens; however, there is no systematic relationship between the microcline content and the distance from the exposed pegmatites. The Lakeview Mountain Tonalite is characterized by abundant oriented inclusions near its contact with the Green Valley Tonalite.

Woodson Mountain Granodiorite: Occurs as a 300-foot long boss near the contact of the two tonalites. The rock is medium to coarse grained, with the major minerals being quartz, microcline, and plagioclase (An_{15-30}). Small veins of quartz are common.

PEGMATITES

The main pegmatite dikes of the Ramona district occur in an area about half a mile wide and 1 mile long. Three major groups of anastomosing dikes, which range in size from a single outcrop several feet in length to dikes half a mile in length, are within this area. These groups include most pegmatites of known commercial interest in the district. The A.B.C. and the Surprise deposits lie to the northwest and southeast, respectively, of the area mapped, and are not described in this report.

Although the pegmatite bodies vary greatly in size and surface expression, all tend to be tabular and most are 2 to 4 feet thick. Pegmatites of commercial interest are slightly thicker than the average. The dikes range in maximum thickness from several inches to about 12 feet.

Pegmatite dikes cut the Green Valley Tonalite and the Lakeview Mountain Tonalite but are not in contact with the Woodson Mountain Granodiorite. They

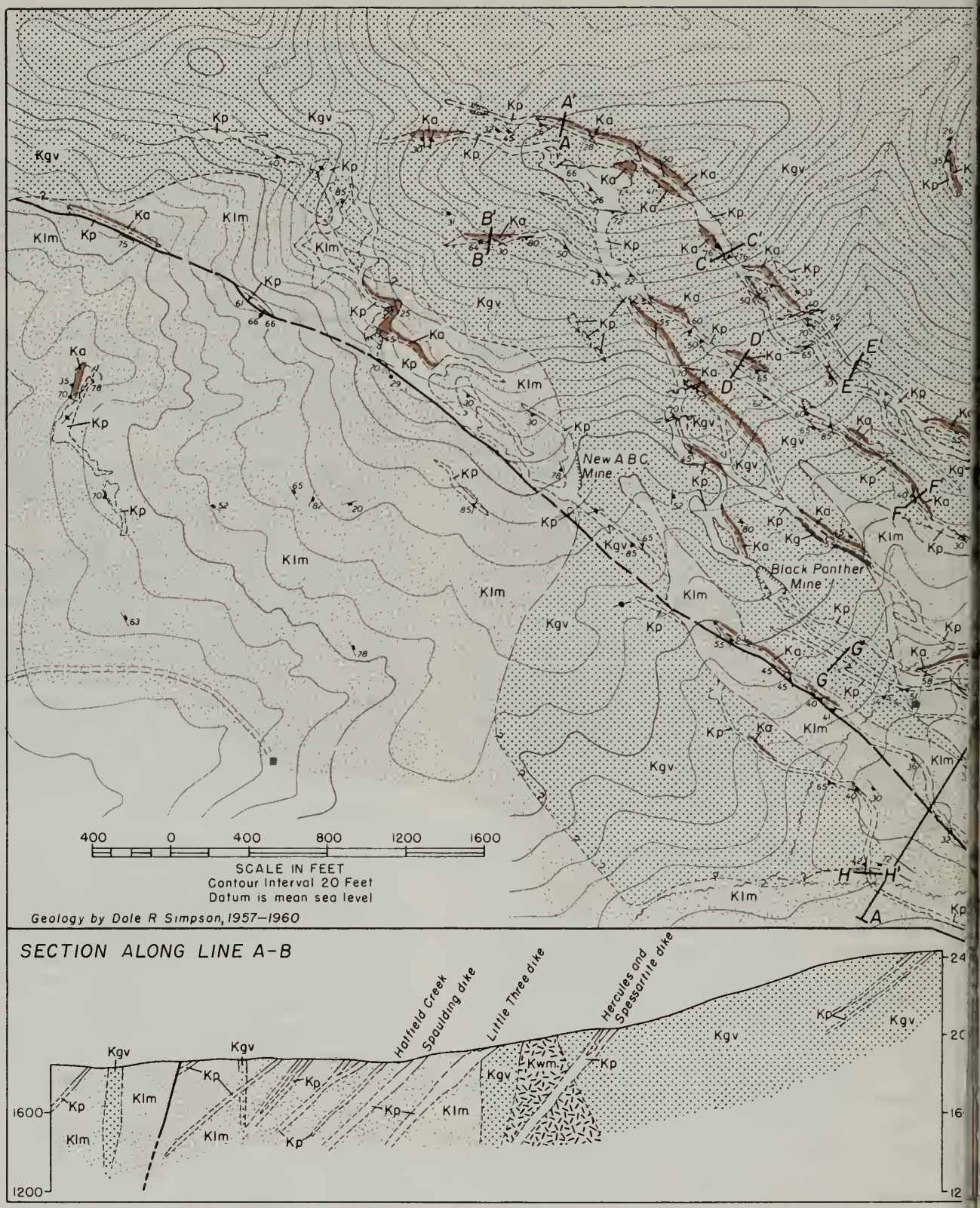
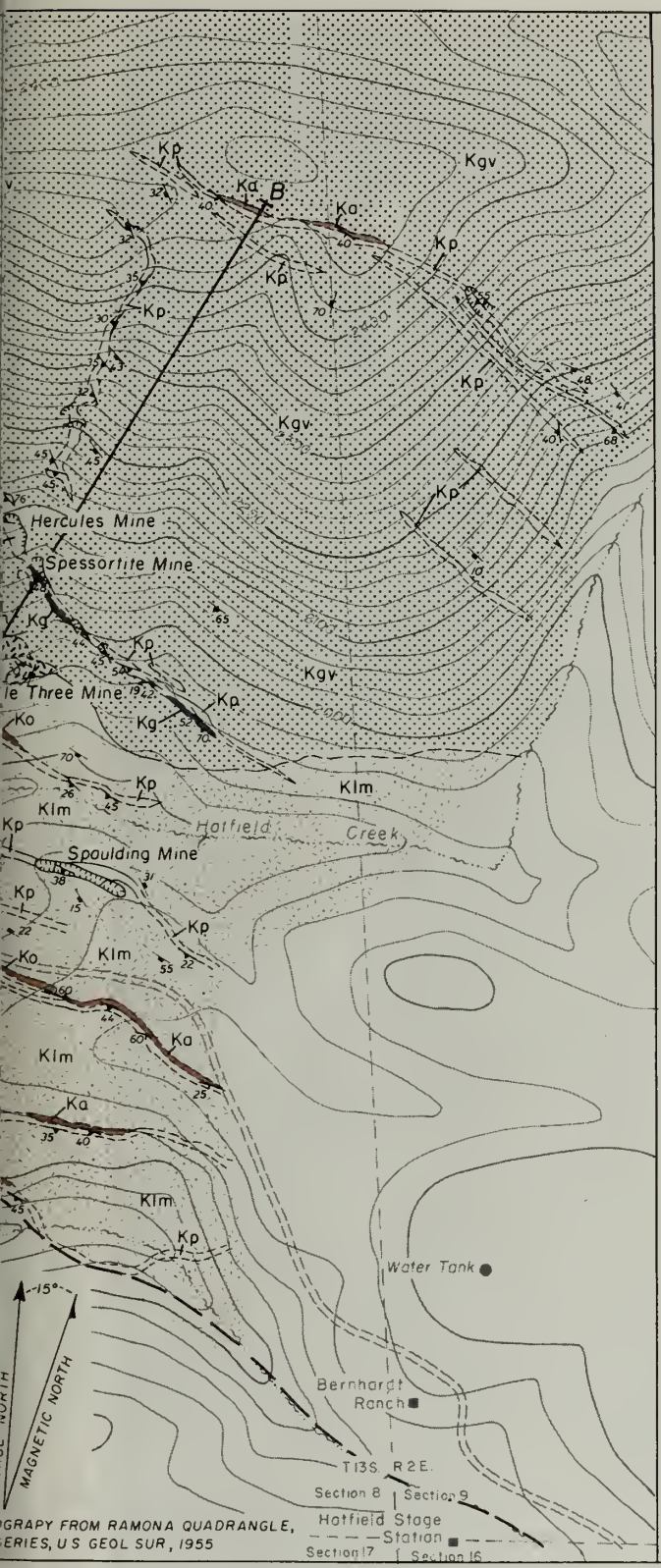


Figure 2. Geologic map and section of the central part of the Ramona pegmatite district.



EXPLANATION

Pegmatite

Kp — Pegmotite undivided

Ko — Line rock
Fine-to-medium groined, sugory textured albite-quortz-microcline-tourmoline pegmatite

Kg — Grophic gronite
Coarse-groined, microcline perthite—quartz pegmatite with minor tourmoline

Kwm — Woodson Mountoin Gronodiorite

Klm — Lokeview Mountain Tonalite

Kgv — Green Valley Tonalite

40 — Strike and dip of pegmotite dikes

40 30 — Strike and dip of pegmotite dikes showing direction and plunge of surfoce undulotion

40 — Strike ond dip of layering in the layered aplites

40 — Strike ond dip of joints

Strike of vertical joints

80 60 — Strike and dip of fault plane showing direction and plunge of slickenside

Shear zone showing dip

Strike of vertical foliation

75 — Strike and dip of cleavage

Contact, *dashed where approximate*

Fault, *dashed where approximate*

Mine workings

Phota 1. Aerial view narth af the central part af the Ramana pegmatite district. Santa Teresa Valley in the backgraund. View is taward the narthwest. N = New A.B.C. mine; B. P. = Black Panther mine; L-3 = Little Three mine; H = Hercules mine; S = Spessartite mine; and Sp = Spaulding mine. *Phota by F. H. Weber, Jr.*

probably are younger than the granodiorite, as suggested by the occurrence of quartz veins, which may be related to the pegmatites, in the granodiorite. Further, dikes of similar pegmatite transect Woodson Mountain Granodiorite in the Pala district (Jahns and Wright, 1951) and the Rincon district (Hanley, 1951) in San Diego County.

The dikes are more resistant to erosion than the country rock, and typically form low ridges along hillsides. Commonly, parts of the dikes are exposed for several hundred feet along their strike, although border portions generally are covered with rock debris.

Dips of the contacts of the pegmatite dikes with country rock range from about 13° to about 70° SW; the average is about 45°. The strike of the pegmatite dikes is also variable but averages about N. 60° W. The general trend of the dikes does not change where the dikes transect the contact between the two tonalites.

The contacts between pegmatite and country rock are sharp; many are irregular in detail, some are nearly planar, and others are broadly and irregularly curved. A particularly well-exposed undulation in the Hercules dike, just downslope from the Hercules adit, plunges 19° west. This undulation is discordant with other structural features such as joints, the contact between the two tonalites, and gneissic segregations.

Type of Pegmatites

Many of the Ramona pegmatite dikes are fine- to medium-grained aggregates of microcline-perthite (hereafter simply referred to as perthite) and quartz, with scattered tourmaline, garnet, and muscovite. Large irregular blocks or euhedral crystals of perthite with some graphically intergrown quartz are scattered randomly throughout these pegmatites.

A smaller number of pegmatite dikes in the district have well-developed internal zoning, in that they consist of two to six lithologically distinct rock units which are arranged asymmetrically (figure 3). The basal zone of these dikes generally consists of albite-rich aplite, with thin layers of tourmaline and garnet ("line rock"), whereas the uppermost zone generally consists of a coarse-grained perthite graphic granite. The central zones are: (1) a granitoid-textured unit that consists predominantly of anhedral quartz and perthite, with abundant tourmaline and garnet, and a small proportion of muscovite (quartz-perthite pegmatite); or (2) a core of albite-quartz pegmatite, characterized by anhedral quartz crystals; or (3) pockets containing euhedral cleavelandite, quartz, topaz, tourmaline, and rare minerals ("pocket pegmatite"). Quartz-cleavelandite fracture fillings and corroded rocks containing spessartite garnet are within the host pegmatite dikes, but are not concordant with them.

These types of pegmatites are discussed below.

Quartz-Perthite Pegmatite

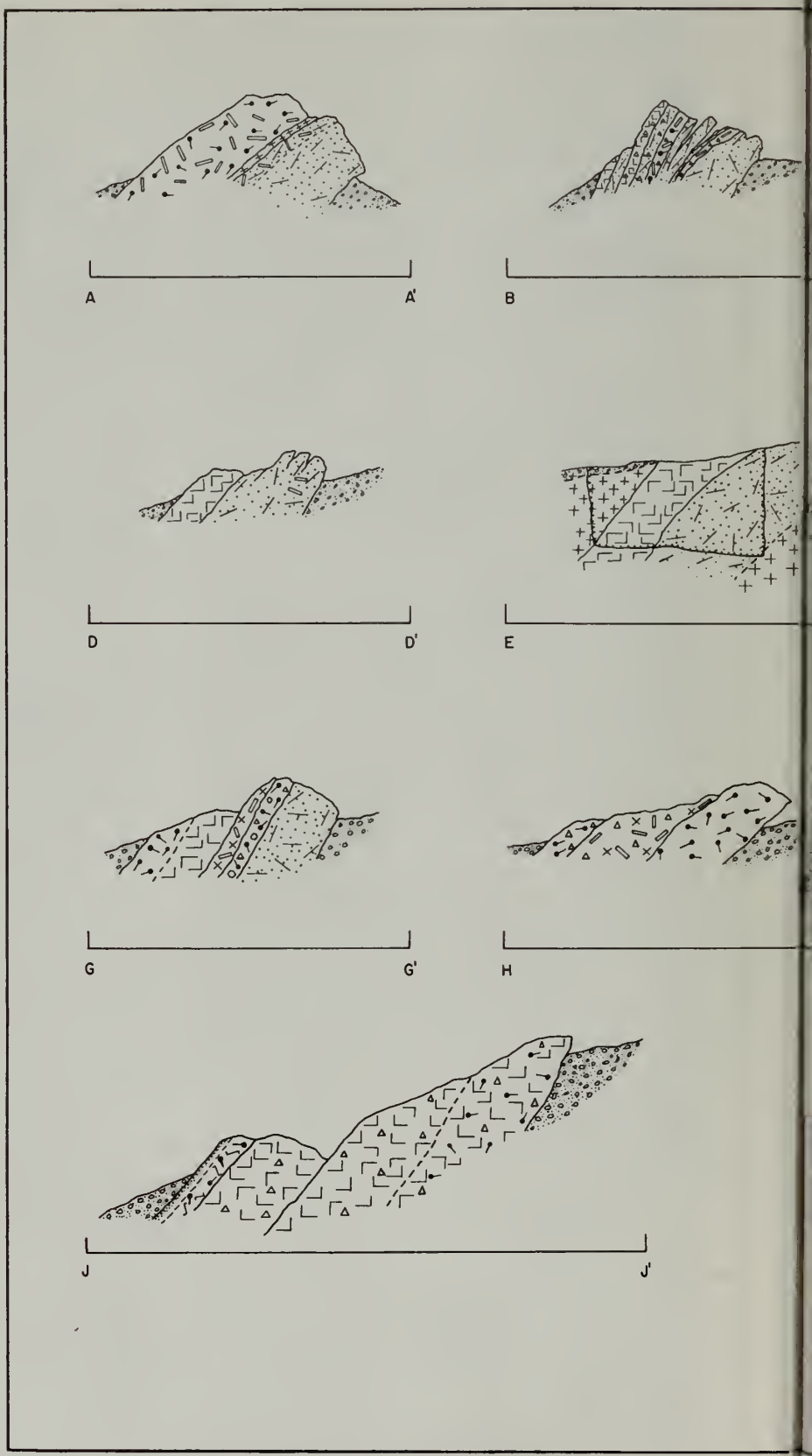
A fine- to coarse-grained [1] quartz-perthite pegmatite rock is the only rock unit comprising the thinner dikes; the same type of rock also occurs as one of the kinds of cores in many of the zoned asymmetrical dikes. This pegmatite consists mainly of quartz and perthite and has, on a large scale, a hypidiomorphic-granular texture. The perthite crystals, typically euhedral, are mainly in a size range of 0.1 to 6 cm and average about 2 cm. Quartz crystals, mostly interstitial to the perthite crystals, are anhedral and average about 1 cm in diameter. The quartz is commonly fractured, and consequently it is easily removed by weathering processes. Albite is sporadically distributed as subhedral to anhedral crystals about 1 to 2 cm in diameter. On weathered surfaces of the rock, this mineral appears white to light gray with no distinctive texture; its weathered appearance contrasts with that of perthite, which is tan and shows a perthitic texture.

Tourmaline, present in minor amounts, is conspicuous as black crystals in a white-gray rock. These crystals generally range from 0.4 to 0.8 cm in diameter and 4 to 6 cm in length. Garnet, tan to red brown, is sporadically distributed in the quartz perthite rocks. Rarely are these garnet crystals larger than 1 cm in diameter. Muscovite is present in books about 1 to 2 cm in diameter by about 0.2 to 0.4 cm in thickness.

A second common variety of quartz-perthite pegmatite has a porphyritic texture. The euhedral phenocrysts of perthite that are characteristic of this rock average about 6 to 8 cm in diameter, and commonly contain inclusions of quartz, tourmaline, and garnet. The quartz inclusions generally are equidimensional, but also may be rod-shaped, and on fractured surfaces may be oriented graphically. Perthite crystals of the groundmass commonly are subhedral to anhedral.

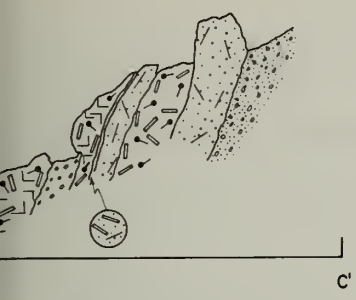
A third variety of quartz-perthite pegmatite contains blocks of graphic granite which give the rock a porphyritic appearance. The mineralogy and texture of the groundmass of this rock type may be similar to either of the previously described rocks. The blocks average about 25 cm in length and 15 cm in width, with edges that commonly appear corroded and embayed. Mineralogically and texturally these blocks of graphic granite are similar to the

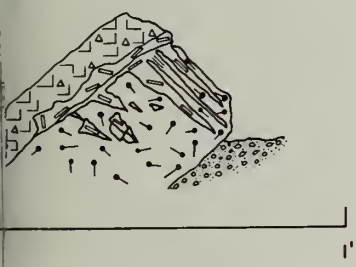
[1] The size classification for pegmatite texture as proposed by Cameron, E. N., and others (1949) is used in this report.



CROSS SECTIONS OF THE RAM

Figure 3.





Geologic cross sections along lines indicated on Figure 2. Sections are oriented approximately southwest to northeast.

0 4 8 12 16

Scale in feet

Prepared by Dole R Simpson, March, 1960

EXPLANATION

Over burden

Line rock
fine-to medium-grained, sugary textured albite-quartz-microcline-tourmaline pegmatite

Graphic granite
coarse-grained microcline perthite-quartz pegmatite, with minor tourmaline.

Quartz-perthite pegmatite
fine- to coarse- grained rock with minor tourmaline and rarely biotite

Border rock
fine- to medium- grained quartz-microcline-plagioclase-biotite pegmatite

Massive quartz

Coarse blocky perthite

Tourmaline

Garnet

Biotite

Tonalite

Contact, dashed where approximate

TES, SAN DIEGO COUNTY, CALIFORNIA

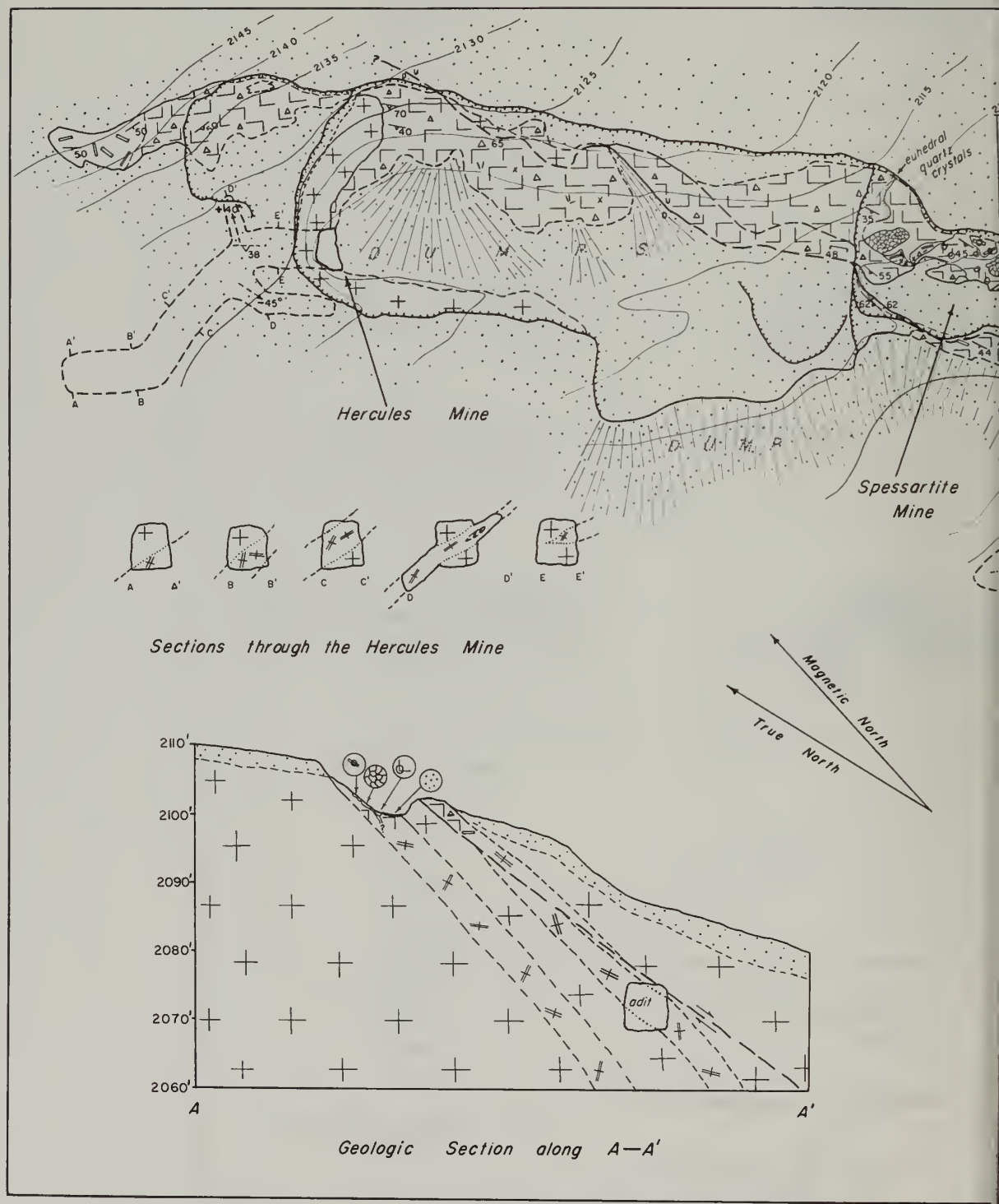
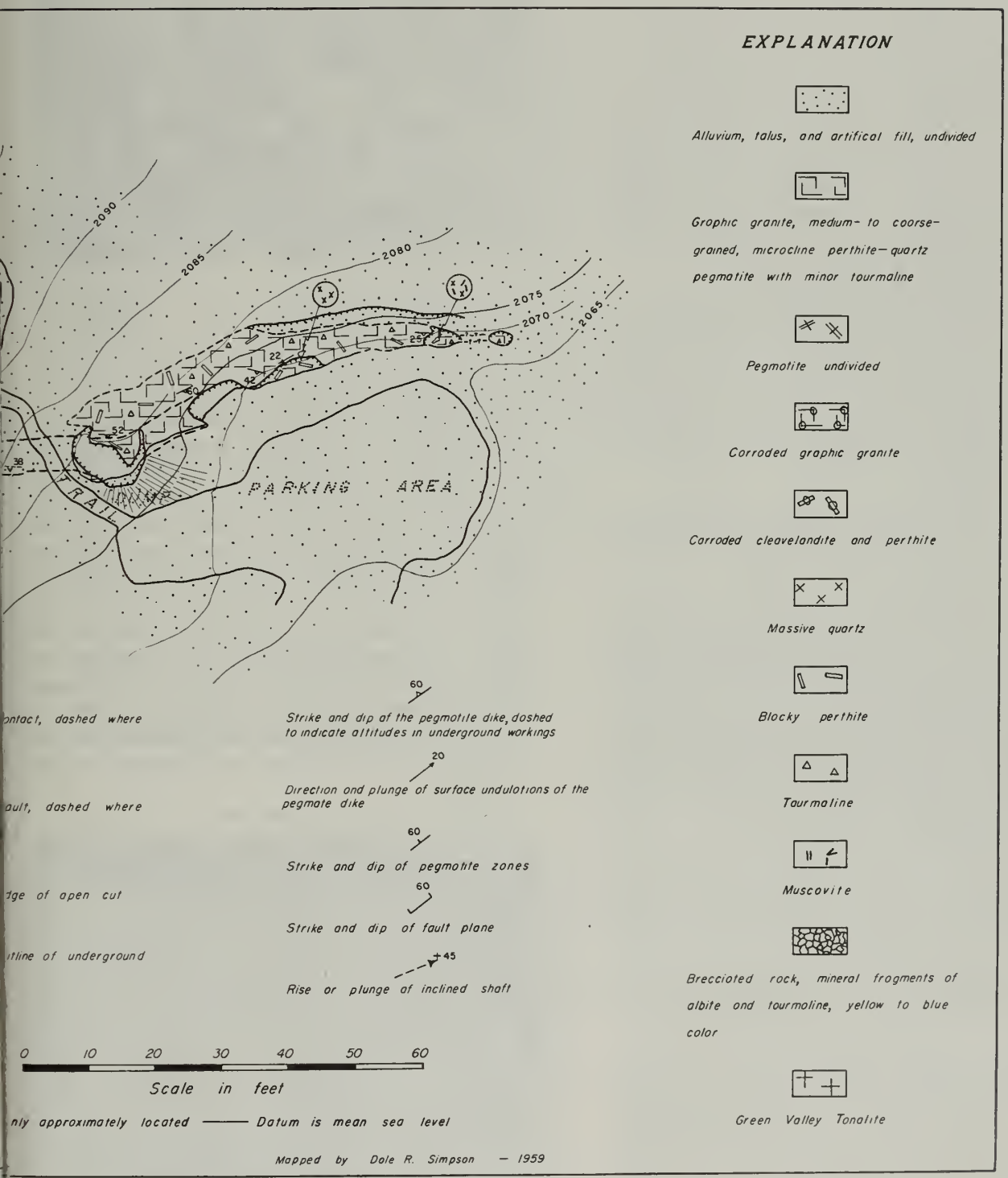


Figure 4. Geologic map and section of the Hercules mine and Spessartite mine.


EXPLANATION
Alluvium, talus, and artifical fill, undivided
Graphic granite, medium- to coorse-grained, microcline perthite—quartz pegmatite with minor tourmaline
Pegmatite undivided
Corroded graphic granite
Corroded cleavelandite and perthite
Massive quartz
Blocky perthite
Tourmaline
Muscovite
Brecciated rock, mineral fragments of albite and tourmaline, yellow to blue color
Green Valley Tonalite
2090
2085
2080
2075
2070
2065
PARKING AREA
RAIL
60
Strike and dip of the pegmatite dike, dashed to indicate attitudes in underground workings
20
Direction and plunge of surface undulations of the pegmate dike
60
Strike and dip of pegmatite zones
60
Strike and dip of fault plane
+45
Rise or plunge of inclined shaft
ontact, dashed where
ault, dashed where
dge of open cut
tline of underground
0 10 20 30 40 50 60
Scale in feet
nly approximately located
Datum is mean sea level
Mapped by Dale R. Simpson — 1959

typical graphic granite that occurs on the hanging wall of the zoned asymmetrical pegmatite dikes.

Layered Aplite ("Line Rock")

Line rock, the local name for a layered aplite, occurs in the zoned asymmetrical pegmatite dikes in sharp contact with the tonalites, and generally on the footwall side of the dikes. The line rock ranges in thickness from several inches to about 4 feet and on an average forms about one-third to one-half of the zoned pegmatite dikes. Overlying the line rock, commonly above a sharp contact, is either graphic granite or coarse-grained pegmatite. Where the upper contact is gradational, the change is one of texture rather than of composition. Blocks of graphic granite, commonly appearing corroded or embayed, are sporadically distributed in the line rock.

The line rock is light gray in general appearance, although individual layers commonly range in color from brown through dark gray to white. The layers, or bands, range in thickness from ⅛ to 1½ inches, with an average of about ⅜ inch. The thicker bands commonly are coarser grained than the narrower ones. All are parallel to subparallel, and are planar to broadly undulatory.

These rocks are distinguished by the typical sugary granular texture of aplites. Dominant minerals are plagioclase, microcline, and quartz. Garnet and tourmaline are present in minor amounts.

Quartz of the line rock occurs in two forms. One form is characterized by equidimensional crystals, hexagonal to rounded in outline, which are about 0.5 mm in average diameter. Crystals of the other form also are equidimensional, but are larger and anhedral, and commonly enclose smaller equidimensional crystals of quartz and feldspar. Most of the larger crystals are about 2 mm in diameter and generally show a marked undulatory extinction.

Albite, the predominant feldspar, also occurs in two forms: smaller, commonly prismatic crystals about 0.5 mm in length; and larger anhedral crystals, 1 to 4 mm in diameter, which commonly enclose smaller crystals of quartz and albite.

Large anhedral crystals of microcline, about 1 to 4 mm in diameter, enclose the small albite and quartz crystals.

Tourmaline, pleochroic from a pinkish purple to dark blue, is present as euhedral crystals with the characteristic rounded triangular cross section. Basal sections of these crystals commonly have an internal zone that is darker blue than the outer zone. A core of feldspar (either microcline or albite) and quartz is present in a small proportion of the tourmaline prisms.

Garnet occurs as euhedral crystals 0.5 mm or less in diameter. Muscovite, in books about 1 mm in diameter, is rarely present in the line rock.

Photo 2. Line rock 57-R-14-4 showing the size distribution of minerals (X 40). K = potassium feldspar, Q = quartz, P = plagioclase, and T = tourmoline. Crossed nicols.

Interpretation of the mineral paragenesis is complicated because of the rhythmic layering of the rock, and because the major constituents were formed during two stages of crystallization. It appears likely that the larger anhedral crystals of quartz, microcline, and albite are later in the crystallization sequence than the smaller euhedral crystals of quartz, albite, tourmaline, and garnet because they enclose the smaller crystals (photo 2). Muscovite and needle-like crystals of tourmaline occur along contacts of the larger anhedral crystals of quartz, albite, and microcline, thus suggesting that this muscovite and tourmaline post-date the large anhedral crystals. The allotriomorphic texture of the larger crystals suggests that these minerals co-crystallized.

The major mineral composition of ten samples of the line rock was determined by making 30 modal analyses (table 2).

Graphic Granite

Graphic granite generally occurs as the uppermost unit within the zoned asymmetrical pegmatite dikes. This hanging wall zone, well developed in the dike at the Little Three mine, reaches a maximum thickness of about 2½ feet. At the Little Three mine, and in the dike shown in cross section J-J′, a thin selvage, listed as "border rock", is found between the graphic granite and the country rock. This selvage is similar to the graphic granite except that it contains minor amounts of biotite. The contact between the graphic granite zone commonly grades downward within a thickness of as much as 2 feet from typical graphic granite to coarse-grained allotriomorphic pegmatite.

Table 2. Modal Analysis of Line Rock From 10 Specimens From the Ramona District

(Area of about 7 cm² on each thin section sampled at 1000 or more points.)

Specimen number	Quartz	Potassium Feldspar	Plagioclase	Tourmaline	Muscovite	Garnet	Total
57–R–14 (1)	41.8	9.6	43.8	4.6	0.0	0.1	99.9
57–R–14 (2)	44.5	12.7	38.1	4.7	0.0	0.0	100.0
57–R–14 (3)	40.4	11.9	40.6	6.5	0.1	0.4	99.9
57–R–14 (4)	40.8	12.1	41.5	4.6	0.1	0.8	99.9
57–R–14 (5)	38.4	9.7	46.0	5.3	0.4	0.0	99.8
57–R–14 (6)	36.1	17.0	41.7	4.9	0.2	0.0	99.9
57–R–14 (7)	37.7	18.6	39.7	4.0	0.0	0.0	100.0
57–R–14 (8)	35.8	13.1	45.6	5.2	0.3	0.0	100.0
57–R–14 (9)	34.6	15.5	43.8	5.7	0.2	0.0	99.8
57–R–14 (10)	35.5	16.9	42.9	4.6	0.0	0.0	99.9
57–R–28 (1)	35.1	13.4	42.0	4.9	1.3	3.3	100.0
57–R–28 (2)	41.3	7.0	41.7	3.7	1.8	4.5	100.0
57–R–28 (3)	24.5	10.1	58.7	3.6	1.0	2.1	100.0
57–R–28 (4)	35.3	9.5	46.7	5.3	1.3	1.8	99.9
57–R–28 (5)	29.6	25.6	36.5	7.3	0.7	0.1	99.8
57–R–28 (6)	32.6	29.3	32.2	5.3	0.3	0.5	100.2
57–R–28 (7)	29.8	22.8	43.0	3.9	0.6	0.0	100.1
57–R–28 (8)	34.9	20.3	36.5	8.1	0.3	0.1	100.2
57–R–28 (9)	27.7	29.6	40.4	2.0	0.1	0.2	100.0
57–R–31 (1)	39.7	29.6	26.7	3.8	0.2	0.0	100.0
57–R–31 (3)	46.9	14.3	38.6	0.0	0.0	0.0	99.8
57–R–31 (5)	44.1	14.6	40.5	0.3	0.3	0.0	99.8
57–R–31 (6)	32.8	18.0	47.2	1.6	0.5	0.0	100.1
58–R–1	32.7	23.9	40.1	3.2	0.1	0.0	100.0
58–R–5	33.3	31.8	31.5	3.1	0.3	0.0	100.0
58–R–9	34.6	20.1	37.3	1.8	6.1	0.1	100.0
58–R–12	33.8	14.7	45.1	5.3	0.1	1.0	100.0
58–R–14	30.2	29.9	35.0	4.9	0.0	0.0	100.0
58–R–15	36.0	4.7	47.3	6.3	0.9	4.8	100.0
58–R–17	32.1	20.2	43.5	4.1	0.0	0.0	99.9
Average	35.8	17.5	41.2	4.3	0.6	0.7	100.1

The graphic granite has two general modes of occurrence. One involves euhedral crystals of perthite with enclosed graphic-shaped rods of quartz; these crystals are scattered through a granitoid or aplitic textured rock. In the other, the entire rock unit consists of graphic granite.

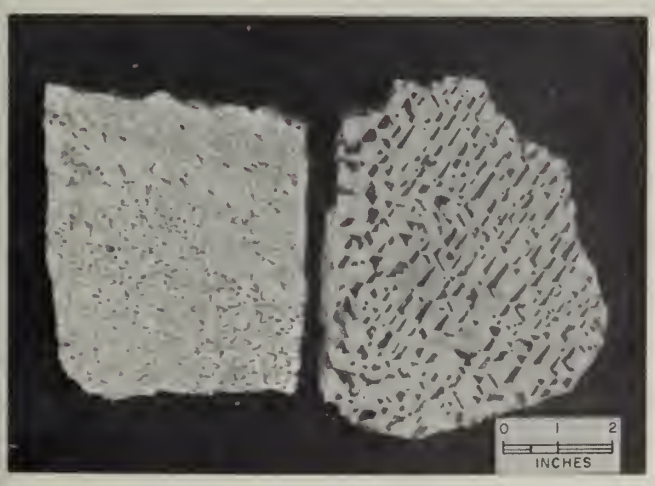


Photo 3. Sowed slobs from specimens of grophic gronite. Within eoch slab the quortz rods hove o common opticol orientation ond the feldspor host is o single crystal.

The graphic granite is a perthite-quartz rock which is light tan to gray on fresh surfaces and tan to brown on weathered surfaces. This rock consists primarily of perthite crystals, anhedral to euhedral in form, ranging in size from about 2 inches to several feet. The perthite is about two-thirds microcline and one-third albite. The albite occurs as irregular platy masses, about 2 to 3 mm in diameter and 0.2 mm thick, rather uniformly distributed in microcline hosts (photo 3).

The second most abundant mineral in the graphic granite is quartz, which occurs as rods and plates in parallel to subparallel orientation. The maximum size of these rods and plates is about 2 cm in diameter by about 30 cm in length; an average size would be about 0.5 cm in diameter by 10 cm in length.

Tourmaline crystals generally about 1 cm in diameter and 4 to 6 cm in length, and garnet crystals, rarely more than 1 cm in diameter, are sporadically distributed through the rock.

As a detailed report on the graphic granite from the Ramona district has been published by the writer (Simpson, 1962), only a brief discussion of the orientation of minerals and the composition of these unusual rocks will be given in this paper.

Most of the quartz rods that appear on surfaces of the graphic granite to be individual rods, are parts of a single crystal, and in most specimens of graphic granite the c axes of the quartz rods are parallel. However, by comparing the orientation of quartz to the orientation of feldspar hosts in each of 18 specimens of graphic granite, it was found that the quartz rods in different specimens are not consistently oriented relative to the crystallographic directions of the feldspar.

Several blocks of graphic granite were mapped in three dimensions by grinding and photographing flat surfaces on each of the blocks. In this manner the shape of the quartz rods within the block of graphic granite could be determined. It was found that the quartz rods within a single specimen branch and unite, thus forming at different levels patterns which are completely different. Because of the numerous interconnections of the quartz rods found within a single specimen, it seems certain that the quartz rods with a similar optical orientation in a specimen are all part of the same quartz crystal.

The gross mineralogical composition of the graphic granite is roughly 25 percent quartz, 55 percent microcline, and 20 percent albite.

Albite-Quartz Pegmatite

Two varieties of albite-quartz pegmatite occur as the central zone material in some asymmetrically zoned dikes. One variety occurs as fracture fillings, and is characterized by feldspar having the habit of cleavelandite. The other variety occurs as irregular masses in which the albite lacks the clevelandite habit.

The fracture fillings transect coarsely crystalline graphic granite, with contacts that are sharp and well-defined by the color contrast of the perthite of the graphic granite and the light blue-green albite of the fracture fillings.

Within the fracture-filling rocks, the quartz is anhedral and extremely inconstant in size, but its crystals average about 5 mm in length. Roughly parallel to the graphic granite contact, the rock contains a layer of euhedral to subhedral quartz crystals about 1.8 mm in diameter by about 3.5 mm in length.

Cleavelandite, also a major mineral in the fracture-filling rocks, forms curved aggregates commonly 4 to 6 mm across. Under the microscope the curved aggregates are seen to have a mosaic texture with each element of the mosaic being a cleavelandite crystal averaging about 0.2 mm in width by 0.4 mm in length. The cleavelandite crystals have fine albite twinning and in thin section some of these twins appear distorted or bent. Other minerals present are microcline, muscovite, tourmaline, and garnet.

Albite-quartz pegmatite occurs as irregular masses in other central pegmatite zones. As seen under the microscope, some of these rocks are similar to the cleavelandite-quartz pegmatite, but others have a subgraphic texture and the albite does not have a cleavelandite form.

Pocket Pegmatite

Pockets or cavities partially lined or filled with euhedral crystals have been found in all zones of the asymmetrically zoned type of pegmatite, but ordinarily are found in the quartz-perthite pegmatite. These pockets range from several millimeters to about 30 cm in diameter and are generally subspherical in shape. Quartz and cleavelandite are the most abundant minerals in these pockets, although tourmaline, topaz, and muscovite are also present. It is primarily from the pockets that prized pegmatite mineral specimens are collected (photo 4). The largest pockets, those that contain the best mineral specimens, occur in the inner units of pegmatite bodies or on the contact between the inner units and the graphic granite or the layered aplite, not within the graphic granite or layered aplite.

Layers of euhedral crystals occur within or between inner units of the pegmatite dikes and are considered to be a variation in form of the pocket pegmatite. These layers, commonly about 3 inches thick, are concordant with the attitude of the dikes but are very irregular in outline. The pegmatite at the Little Three mine contains a layer of euhedral crystals which is several feet wide and about 6 feet long. This layer is labeled pocket pegmatite, on the map of the pegmatite at the Little Three mine (figure 5). The mineralogy of this layer is similar to that described above for the pockets of euhedral crystals. Many of the pockets contain little open space, because they are filled with crystals in contact with one another, with loose crystals, or with clay.

It is difficult to define the limit of the pocket pegmatite because it apparently does not make distinct contacts with other pegmatite rocks. In this study the limit of the pocket pegmatite is defined as the base of those minerals with well-formed crystal faces which jut out from the walls of the pocket pegmatite.

Three areas of the pocket pegmatite at the Little Three mine were sampled. These samples were the basis of the following mineralogical descriptions and estimates of bulk composition (table 3).

Sample 57-R-2 is a collection of three specimens of quartz and cleavelandite. The largest specimen is 15 cm long by 8 to 10 cm in diameter. Megascopically these specimens, from the euhedral-crystal layer of the Little Three dike, are representative of other quartz-cleavelandite specimens from pocket pegma-

Photo 4. Pocket minerals in place ot Little Three mine. Minerols are smoky quortz (q), topoz (t), ond olbite voriety cleavelandite (c). Note the sondy textured surfaces on some of the minerals. The largest topoz crystal, on the right, is about 2 inches long. *Photo by F. H. Weber, Jr.*

tites. The cleavelandite occurs as aggregates of radiating blades as much as 2 cm in length and width by 2 mm in thickness. Euhedral crystals of quartz about 6 cm in diameter, commonly terminated, project from the cleavelandite aggregate. The base of the projecting quartz crystals is intergrown with the cleavelandite. Trapezohedral faces are poorly formed on the quartz. This mineral shows a light smoky color. Many of the crystal faces have a tan coating or are lightly frosted. A single crystal of schorlite about 1 cm in diameter is present on a fractured surface of one of the specimens.

A surface coating, generally about 0.5 mm in thickness, is present on the quartz and cleavelandite. Microscopic examination reveals that the coating consists of colorless euhedral crystals of tourmaline, probably elbaite, cemented by minute plates of lepidolite. Commonly the tourmaline crystals are doubly terminated, reaching a maximum size of about 0.2 mm in length by about 0.07 mm in width.

The composition of this specimen was estimated by laying a one-quarter-inch grid over the top and bottom of each of the three fragments and then point-counting the minerals that fall under the cross lines. A total of more than 600 points were counted.

Samples (57-R-3 and 57-R-9) from the other two areas are similar to the samples described except that the minerals are present in different proportions, and topaz is present. The mineralogical composition of these two samples was determined by the method previously described. Potassium-bearing minerals, such as muscovite and potassium feldspar, are very rare or absent.

Corroded and Secondarily Mineralized Rocks

A suite of cavernous feldspar rocks containing little or no quartz was collected from the Spessartite dike (see figures 2 and 4). Because some of the rocks consist of white crenulated masses of cleavelandite, they are locally called "cottonball spar" and are accepted by the miners as a field indication of spessartite mineralization. Good examples of the cavernous or corroded rocks are found in all zones of the pegmatite except the line rock. The attitude of the area of corrosion is not concordant with the attitude of zones in the pegmatite as is clearly shown at the Spessartite dike. Because of this discordant attitude and the veining relationships, the period of corrosion is regarded as being later than the period of formation of the pegmatite zones.

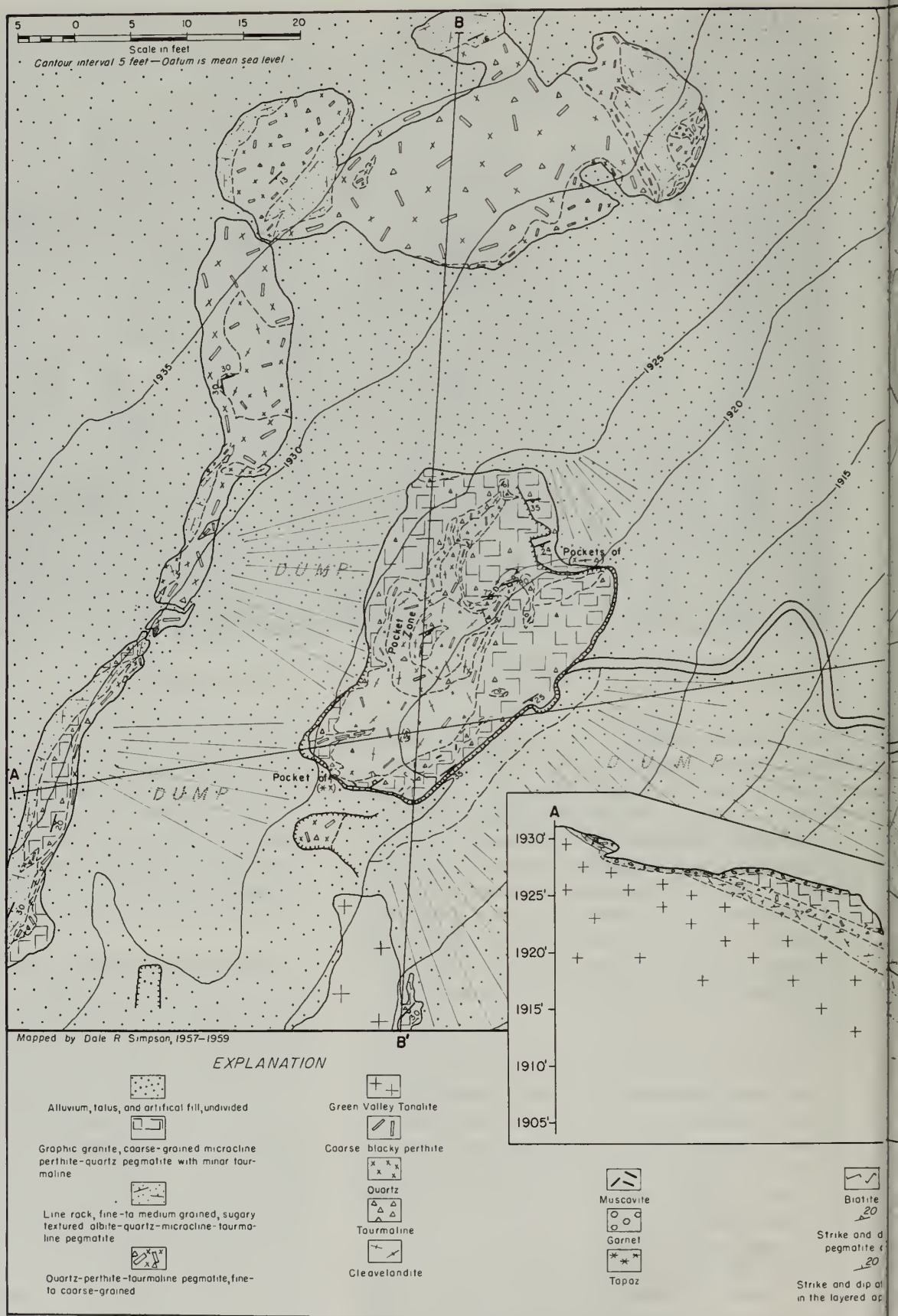


Figure 5. Geologic map and cross sections of the Little Three Mine, San Diego County, California.

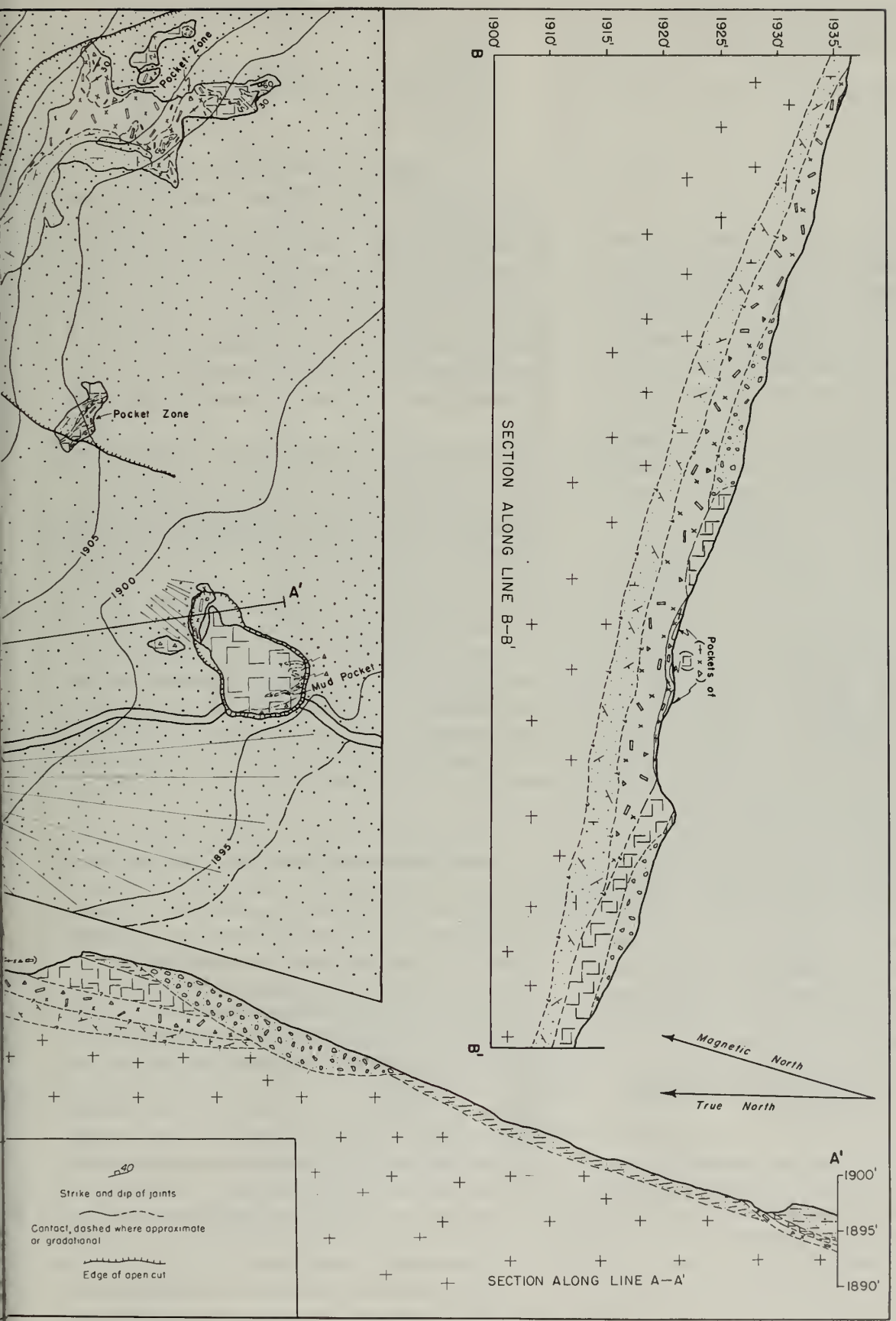

Pocket Zone
Pocket Zone
1905
1900
A'
Mud Pocket
1895
B
B'
1900'
1910'
1915'
1920'
1925'
1930'
1935'
SECTION ALONG LINE B–B'
Pockets of
Magnetic North
True North
A'
1900'
1895'
1890'
SECTION ALONG LINE A–A'
40
Strike and dip of joints
Contact, dashed where approximate or gradational
Edge of open cut

Table 3. Approximate Bulk Composition of Samples of Pocket Pegmatite in Volume Percent

Specimen number	Quartz	Cleavelandite	Tourmaline	Topaz
57-R-2	43	57	1	--
57-R-3	80	13	2	5
57-R-9	94	4	tr.	2

Megascopically, these corroded rocks can be divided into three general categories. The first category is similar to graphic granite but with voids instead of quartz rods. The feldspar appears fresh, with reflecting cleavage surfaces that commonly show a perthitic structure. Tourmaline is commonly present in these rocks as black vitreous crystals which reach a maximum size of about 2 cm. On cut surfaces many of the larger tourmaline crystals show a yellow border zone. Small terminated quartz crystals are rarely found in the graphic or rod-shaped holes. The rock is thought to be a relic graphic granite.

The second category of corroded rocks is a blue-white cleavelandite rock in which the crystals have a coxcomb structure. Tourmaline is rarely present in these rocks.

The third category of corroded rocks consists of euhedral perthite crystals. Crystal faces and fractured surfaces have a fin-like appearance caused by thin blades of feldspar projecting beyond less-corroded parts of the crystals. White albite is present as veins and it also armors holes that were probably former sites for quartz rods. Typical examples of the three types of corroded rock are shown in photo 5.

Secondary quartz, albite, orthoclase (variety adularia), garnet, and tourmaline have crystallized in the corrosion cavities of all these rocks. Large concentrations of spessartite are also found in the corroded rocks, either in a blue-gray clay also containing tourmaline needles, or in cavities and fractures. Muscovite is noticeably absent as a secondary mineral, and if ever present as a primary mineral in the areas of corroded rocks, it has been completely removed.

MINERALOGICAL AND CHEMICAL COMPOSITION OF THE PEGMATITES

An approximation to the bulk composition of the pegmatites was obtained by making dimensional measurements of the pegmatite units or zones, determining the proportion of the minerals in these units, and determining or assuming the composition of the mineral species for ten selected areas of the dikes. The composition is about that of an average granite except for the presence of 3.5 per cent tourmaline (tables 4 and 5).

Table 4. Average Model Analysis of Ten Areas of Pegmatite

Quartz	31.1
K-feldspar	33.1
Albite	31.2
Tourmaline	3.5
Garnet	0.4
Muscovite	0.5

ORIGIN OF THE PEGMATITES

The pegmatite dikes at Ramona appear to have been injected as a liquid, possibly with a vapor phase, and crystallized in place without significant replacement or alteration of the country rock because of (1) their occurrence well within granitic rocks of the southern California batholith, (2) the lack of correlation of structure, texture, thickness, mineralogy, or bulk chemical composition with the country rock, and (3) the sharp contacts between the pegmatites and tonalites.

The layered aplite generally occurs on the footwall sides of the dikes and contains included blocks of graphic granite and euhedral graphic perthite crystals. In addition, zones of graphic granite and other coarse-grained pegmatite units commonly contain stringers of layered aplite. Therefore, it seems most likely that the graphic granite and layered aplite either cocrystallized or crystallized during alternating sequences.

Ideally, the graphic granite and the layered aplite form opposite wall zones of the pegmatite. Because these zones show no evidence of having replaced earlier units, they are considered to be the oldest zones in the pegmatites; because the quartz-perthite pegmatite zone lies between these outer zones, it must be younger.

Cores composed wholly of quartz are very rare in the Ramona pegmatites. Where such cores are found, they lie between the quartz-perthite pegmatite and the layered aplite, or in the quartz-perthite pegmatite. Consequently, these quartz cores are considered younger than the quartz-perthite pegmatite.

As quartz-albite and quartz-cleavelandite rocks occur as veins cutting graphic granite and also as anhedral masses and veins in the quartz-perthite pegmatite, they are considered to be younger than the host rock. Spatial relationships were not determined between quartz cores and the quartz-albite rocks; but because other concordant units almost surely predate discordant ones, the concordant quartz cores probably predate the discordant quartz-albite rocks.

Because pocket pegmatite occurs in or between all other pegmatite units, it is considered to be the last primary material to crystallize.

Deuteric alteration and secondary mineralization followed the formation of the primary units in the pegmatites, as is shown in the Spessartite ledge where an

Table 5. Bulk Composition of the Romona Pegmatites Compared With Analyzed Samples of the Pegmatite and Granites

	Average Ramona pegmatites[a]	Layered aplite sample 57-R-28[b]	Quartz-perthite pegmatite sample 57-R-46[c]	Average alkali granite[d]	Average per-alkaline granite[d]
SiO_2	74.9	73.53	----	73.86	71.08
Al_2O_3	14.2	15.03	----	13.75	11.26
TiO_2	tr	0.06	----	0.20	0.40
P_2O_5	----	n.d.	----	0.14	0.07
Fe_2O_3	----	0.41	----	0.78	4.28
FeO	0.5	0.75	----	1.13	2.19
MnO	0.3	0.32	----	0.05	0.11
MgO	tr	0.10	----	0.26	0.25
Li_2O	----	0.01	0.20	----	----
CaO	0.5	0.56	----	0.72	0.84
Na_2O	3.5	5.01	4.69	3.51	4.92
K_2O	5.5	2.96	2.67	5.13	4.21
Rb_2O	----	0.00	----	----	----
Cs_2O	----	0.00	----	----	----
H_2O^+	0.2	0.44	----	0.47	0.39
H_2O^-	----	0.24	----	----	----
CO_2	----	n.d.	----	----	----
F	----	0.01	----	----	----
B_2O_3	0.4	----	----	----	----
	----	99.43[e]	----	----	----

[a] Analysis calculated from modal data of average Ramona pegmatites.
[b] Layered aplite. C. O. Ingamells, analyst.
[c] Partial analysis of quartz-perthite pegmatite by flame photometry. Art Chodos, analyst.
[d] Quoted from Nockolds, S. R., 1954, Chemical composition of igneous rocks: Geological Society of America, Bull. 65, pp. 1012-1013.
[e] The amount of B_2O_3 indicated by the modal tourmaline in the sample is 0.48 percent.

alteration zone cuts and replaces the graphic granite, quartz-perthite pegmatite, and pocket pegmatite.

The origin of the layering in the footwall aplite is a problem common to many pegmatite districts. Such layering may be the result of rhythmic crystallization induced by pressure changes as a result of pulsatic, forceful injections of the pegmatitic magma into a confining chamber. The large anhedral crystals of quartz, microcline, and albite in the layered aplite may be late-stage products of crystallization of vapor or melt that was interstitial to the small euhedral crystals.

Field relations indicate that the graphic granite zone formed concurrently with the layered aplite zone. Thus, it seems likely that at the same time the graphic granite crystallized from the vapor (as suggested by Simpson, 1962) the layered aplite crystallized from a magma. In this way the total crystallizing system from the coexisting magma and vapor could compositionally be about the same as the thermal minimum in the system $NaAlSi_3O_8.KAlSi_3O_8.SiO_2H_2O$ (Tuttle and Bowen, 1958).

The origin of the quarz-perthite pegmatite is problematic because it occurs with large variations. The two most noticeable textural features of the rock are its abundant euhedral crystals of perthite and its rare irregular blocks of graphic granite. A possible explanation for the blocks of graphic granite in the quartz-perthite pegmatite as well as the layered aplite is that they became detached from the hanging walls of the dikes and settled into the crystallizing magmas. The irregular outline of the graphic granite blocks may be the result of overgrowths rather than corrosion, and the phenocrysts of perthite in these rocks may have crystallized from vapor bubbles rising or streaming through a silicate melt.

The pocket pegmatite, quartz-albite, and quartz-clevelandite rocks do not show widespread pseudomorphism of earlier minerals, nor do they contain evidence of relic structures or textures of pre-existing rocks, thus negating a replacement origin. Instead, the presence of euhedral crystals of pocket pegmatite projecting into cavities suggests that these rocks crystallized from a vapor or aqueous liquid phase.

MINES

Although six gem mines are named on figure 2, and a number of other places have been prospected, only the Little Three and Spessartite mines are described here. These two mines are typical of those in the area, and are among the best developed.

Little Three Mine

The Little Three mine, about 600 feet north of Hatfield Creek, develops one of the major dikes of the district (figure 5). Mining has been carried on principally from three irregular surface openings. Two of these openings are roughly 30 feet in diameter, and the third is about 10 feet in diameter.

The dike, as exposed in the most northerly cut, is about 6 feet thick, and where it has been mined, ap-

pears to average about 4 to 5 feet. The dike strikes northwest and dips 13 to 30 degrees to the southwest. An average dip is about 20 degrees. The country rock exposed in the most northerly cut is Green Valley Tonalite; however, the dike exposed in the most southerly cut and also the easterly cut appears to be on or very near the contact between the Green Valley Tonalite on the north and the Lakeview Mountain Tonalite on the south. The pegmatite-tonalite contact is sharp.

The dike consists mainly of graphic granite, line rock and quartz-perthite pegmatite. Graphic granite, constituting about one-third of the rock body, is in a zone ranging in thickness from about 6 inches to 2 feet, in the hanging wall portions of the dike. Tourmaline, garnet, and muscovite are sporadically distributed in this rock.

Line rock, occurring mostly in the footwall portions of the dike, also forms about one-third of the rock body. Overlying the line rock is quartz-perthite pegmatite. Pocket pegmatite is primarily in the quartz-perthite pegmatite and in rocks near the contact between the quartz-perthite pegmatite and graphic granite. Prized specimens of tourmaline, topaz, quartz, and cleavelandite are obtained from these pockets. Pockets found entirely within the graphic granite generally contain only mica.

Most of the mineral specimens were obtained from the two larger cuts. Only clays and mud with some abraded crystals of quartz and tourmaline were obtained from a single cavity in the smallest of the three cuts. This cavity appears to be a pocket pegmatite zone in which the minerals have been pervasively weathered or altered.

Spessartite Mine

The Spessartite mine is of particular interest because the total output of garnet produced from it is about equal to the total produced from all of the other mines of the district (figure 4). This deposit was first opened in 1959; however, Mr. L. B. Spaulding, the owner and operator of the mine, indicated (personal communication) that there is evidence that the dike had been prospected at some earlier time. The Hercules claim on the same dike, 75 feet north, was located in 1903.

The mine has been worked by an open cut which extends along the strike of the dike about 40 feet and down dip about 15 feet. The dike is about 5 feet thick, and where exposed by the open cut it strikes northwest and has a southwesterly dip.

The dike lies in Green Valley Tonalite, and the contact between the tonalite and the pegmatite is sharp. A small normal fault, striking roughly north and dipping 48 to 60 degress westerly, is exposed in the open cut. North of the open cut, the fault transects the dike at a low angle. It is unlikely that movement along the fault has affected the dike down dip from the open cut.

The zoning of this dike is similar to that of the other asymmetrically zoned dikes of the district. Most of the lower part of the dike consists of line rock with layers rich in tourmaline; the upper one-quarter to one-half is composed of coarse-grained graphic granite. This graphic granite commonly contains tourmaline and blocks of perthite without graphic intergrowths of quartz. Cleavelandite, tourmaline, and quartz crystals are found in the central part of the dike, muscovite is sporadically distributed, but is not found in the immediate vicinity of the mine.

Rocks of the central part of the dike in the vicinity of the mine opening show evidence of corrosion and replacement. The corroded and replaced rock unit is irregular in shape and transects all zones of the dike except the line rock.

Quartz is rarely found in the corroded rocks, and microcline in crystals of perthite appears embayed. Except for these features, the corroded rocks appear to be the counterpart of the graphic granite, the quartz-cleavelandite rock, and the quartz-perthite pegmatite.

Intimately associated with, and even filling some of the cavities of the corroded rock, is a brecciated rock which is blue gray and consists mostly of angular fragments of feldspar and tourmaline with clay. These angular fragments average about 0.03 mm in maximum dimension. It is in the brecciated rock and the corroded rock that the spessartite is found.

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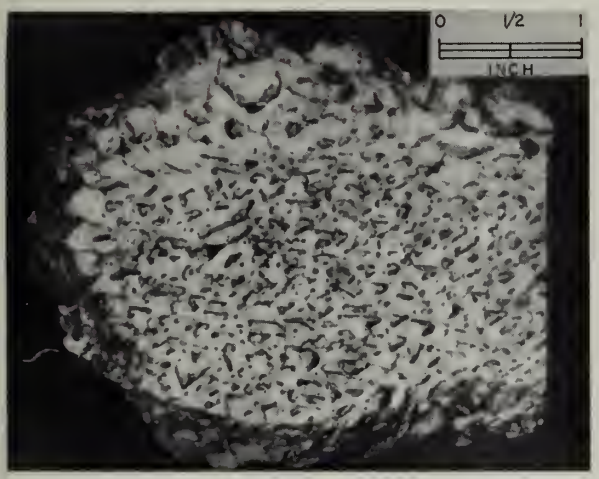
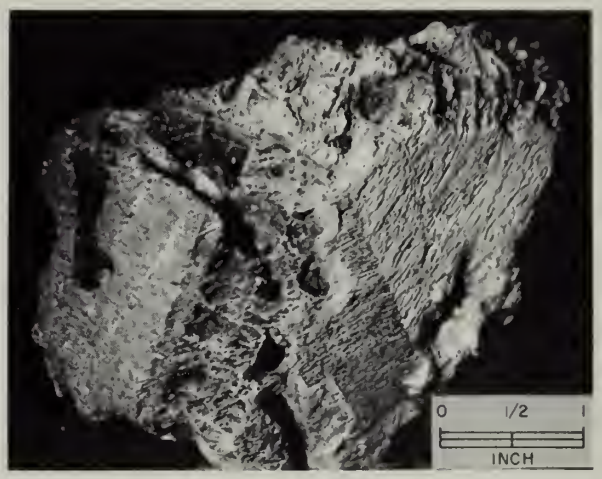
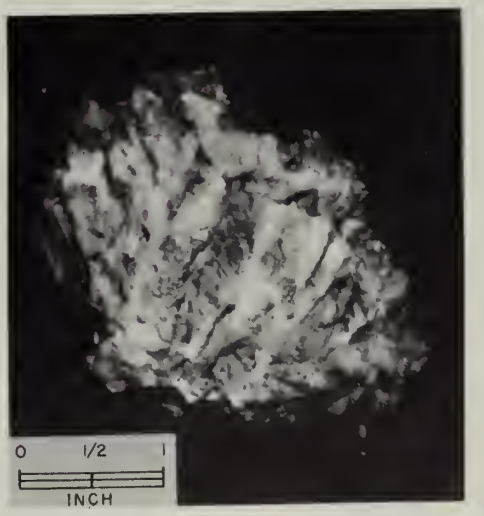


CORRODED GRAPHIC GRANITE



CORRODED TWINNED PERTHITE CRYSTAL



CORRODED CLEAVELANDITE ROCK

Photo 5. Corroded rocks from the Romono pegmotites.

Tertiary Stratigraphy of the Church Creek Area, Monterey County, California*

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ABSTRACT

The Church Creek area is in the northern Santa Lucia Range about 125 miles south of San Francisco, California. The range core consists of pre-Tertiary metamorphic and granitic rocks traversed by a system of northwesterly trending Plio-Pleistocene reverse faults. Down-faulted homoclines of lower Tertiary strata are exposed adjacent to the faults and rest unconformably on the metamorphic rocks.

The following stratigraphic units are present in the mapped area: (1) 750 to 1000 feet of Paleocene sandstones, mudstones, and conglomerates; (2) 0 to 150 feet of middle Eocene Junipero Sandstone of probable Penutian age; (3) 0 to 250 feet of middle to upper Eocene Lucia Mudstone of Ulatisian age; (4) 400 to 800 feet of upper Eocene The Rocks Sandstone of Ulatisian to Narizian age; and (5) about 1250 feet of upper Eocene to Oligocene Church Creek Formation (new name) comprising interbedded sandstone, siltstone, and mudstone of Narizian and Refugian age. These strata had been mapped together previously as "Eo-Oligocene Church Creek beds" and as "Miocene Vaqueros-Temblor sandstone". The Miller Creek and Church Creek reverse faults dip an average 60°–65° NE and have a minimum displacement of half a mile to 1 mile. The east-west and vertical Willow Creek fault was active first (?) in the early Eocene and was reactivated as a transverse tear fault during the time of movement on the reverse faults.

INTRODUCTION

Location and access. The Church Creek area is approximately 125 miles south of San Francisco in the northern Santa Lucia Range of Monterey County. The Santa Lucia Range trends northwesterly, parallel and adjacent to the California coast, from San Luis Obispo to Monterey Bay (Taliaferro, 1943a, p. 119). The range is bordered on the east by the broad alluvial valley of Salinas River. The Church Creek area spans the divide between the drainage of Carmel River, which flows northwest to enter the Pacific Ocean at Carmel Bay, and that of Arroyo Seco, which is tributary to Salinas River. The mapped area is one of high, steep ridges separated by deep, narrow canyons. Elevations range from 1000-2500 feet in the valleys to 4000-5000 feet on the higher ridges.

An all-weather road up Arroyo Seco, from Greenfield in Salinas Valley, affords easy access to the eastern edge of the mapped area. The road from Jamesburg, a point easily reached from Monterey via Carmel Valley, to Tassajara Hot Springs is the only route into the central part of the mapped area. The Tassajara Road is intermittently blocked by snow and flood damage during the winter months, is often hazardous in wet weather, and may be impassable in early spring before winter storm damage is repaired. Private roads into Church Creek and Miller Canyon and U.S. Forest Service trails are the only routes of travel into the western part of the area.

The mapped area includes portions of the U.S. Geological Survey Ventana Cones, Chews Ridge, and Tassajara Hot Springs 7½-minute topographic quadrangles.

Geologic setting. The core of the northern Santa Lucia Range consists of metamorphic rocks which are intruded locally by granitic plutons. As discussed by Trask (1926), Reiche (1937), Fiedler (1944), and Compton (1960a), the metamorphic rocks are foliate, coarse-grained, metasedimentary and subordinate metavolcanic rocks of the amphibolite, and locally granulite, facies. The principal rock types, in approximate order of their abundance, are: quartzo-feldspathic and calcsilicate granofels and gneiss, amphibolite, biotitic schist, and marble. The granitic rocks that intrude the metamorphic rocks range from quartz monzonite to quartz diorite in composition. Small aplite and pegmatite bodies are common in the metamorphic terrane. Several of the granitic bodies have been dated as Late Cretaceous by the potassium-argon method (Curtis, Evernden, and Lipson, 1958, p. 9, 13-16).

Sequences of Upper Cretaceous and Tertiary strata rest unconformably on the metamorphic and granitic rocks. Along the northeastern flank of the range,

* Based on a Master of Science thesis submitted to Stanford University in 1956. Manuscript submitted for publication 1959.

Photo 1. Upper valley of Church Creek; view northwest from massive sandstone lens (center to lower right) in the Church Creek Formation near Tassajara Road. The Church Creek fault posses through Church Creek Divide (skyline notch) and along the base of the steep slopes of the ridge on the right. This ridge is composed of crystalline rock. The floor of Church Creek valley is underlain by Church Creek Formation. Junipero Sandstone, Lucia Mudstone, and The Racks Sandstone, exposed as dip slopes and flatirons, rest unconformably on crystalline rock on the ridge to the left.

these strata occupy synclinal basins which are, in part, downfaulted. The Church Creek area lies along the deeply eroded backbone of the range where only the older sequences of sedimentary strata have escaped erosion, and these only in deeply downfolded or downfaulted segments of synclines or fold limbs. The northwesterly trend of isolated outcrop bands reflects the structural grain of fold axes and major reverse faults.

Previous geologic work. Published geologic maps covering most of the northern Santa Lucia Range at the scale of 1:62,500 have been available for many years. The Church Creek area lies within the Jamesburg and Lucia 15-minute quadrangles mapped by Fiedler (1944) and Reiche (1937). The Santa Cruz sheet of the Geologic Map of California (Jennings and Strand, 1958) incorporates the mapping presented in this report as a modification of the older work.

The mapping of Trask (1926) in Point Sur quadrangle, west of the Church Creek area, first showed that reverse faults of northwesterly trend and great displacement dominate the structural pattern of the northern Santa Lucia Range. The mapping of Reiche (1937) and Fiedler (1944) served to delineate the traces of the major faults and outlined isolated exposures of downfaulted sedimentary rocks in homoclines and synclines. More recently, unpublished mapping by Compton (1960b), in the Junipero Serra quadrangle southeast of the Church Creek area, has revealed the close geometric relationship between faults and folds, and promises to yield the first well integrated analysis of the structural development of the range.

Type localities of two of the most widespread formations in the central Coast Ranges are on the flanks of the Santa Lucia Range. The type locality

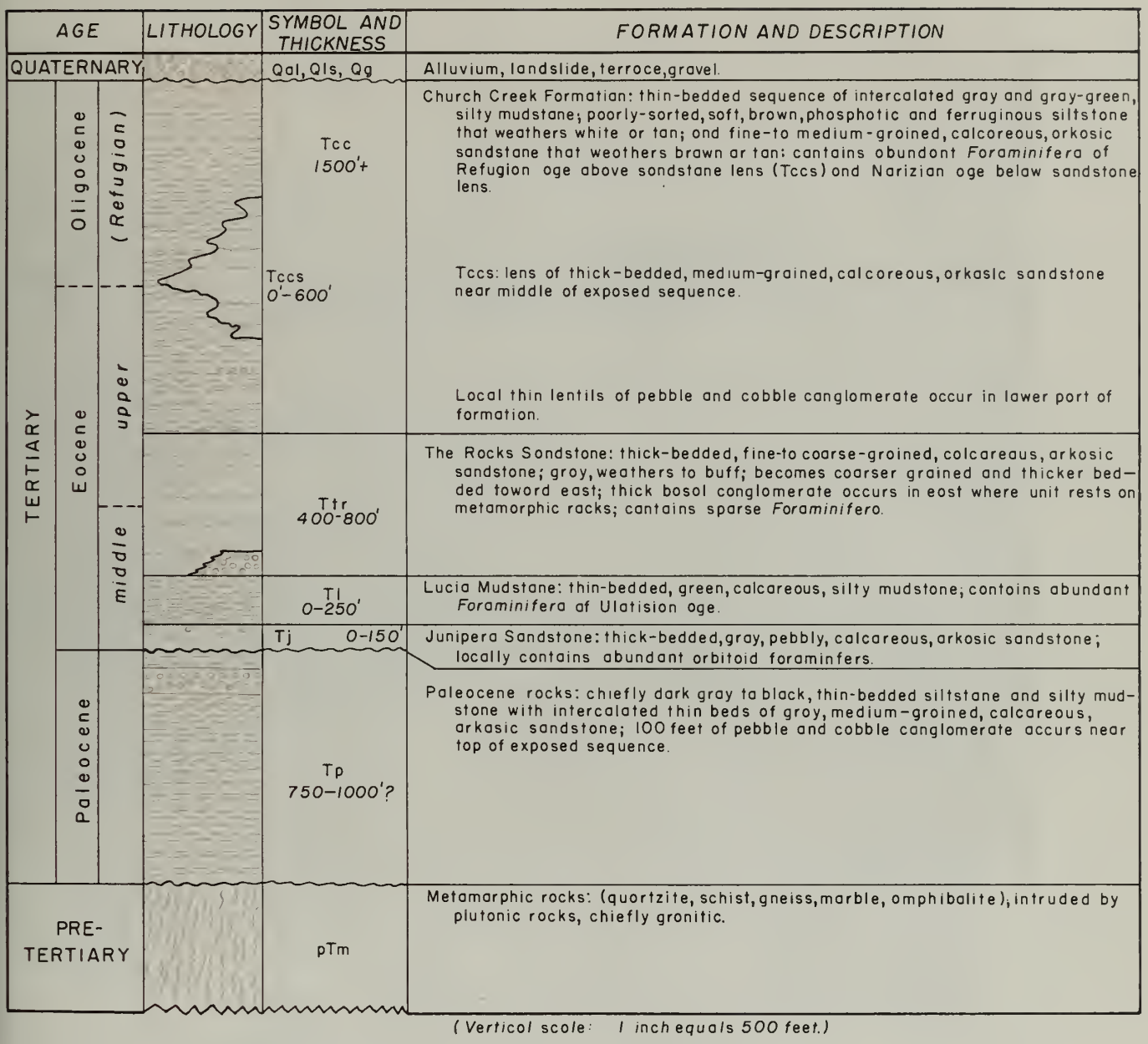
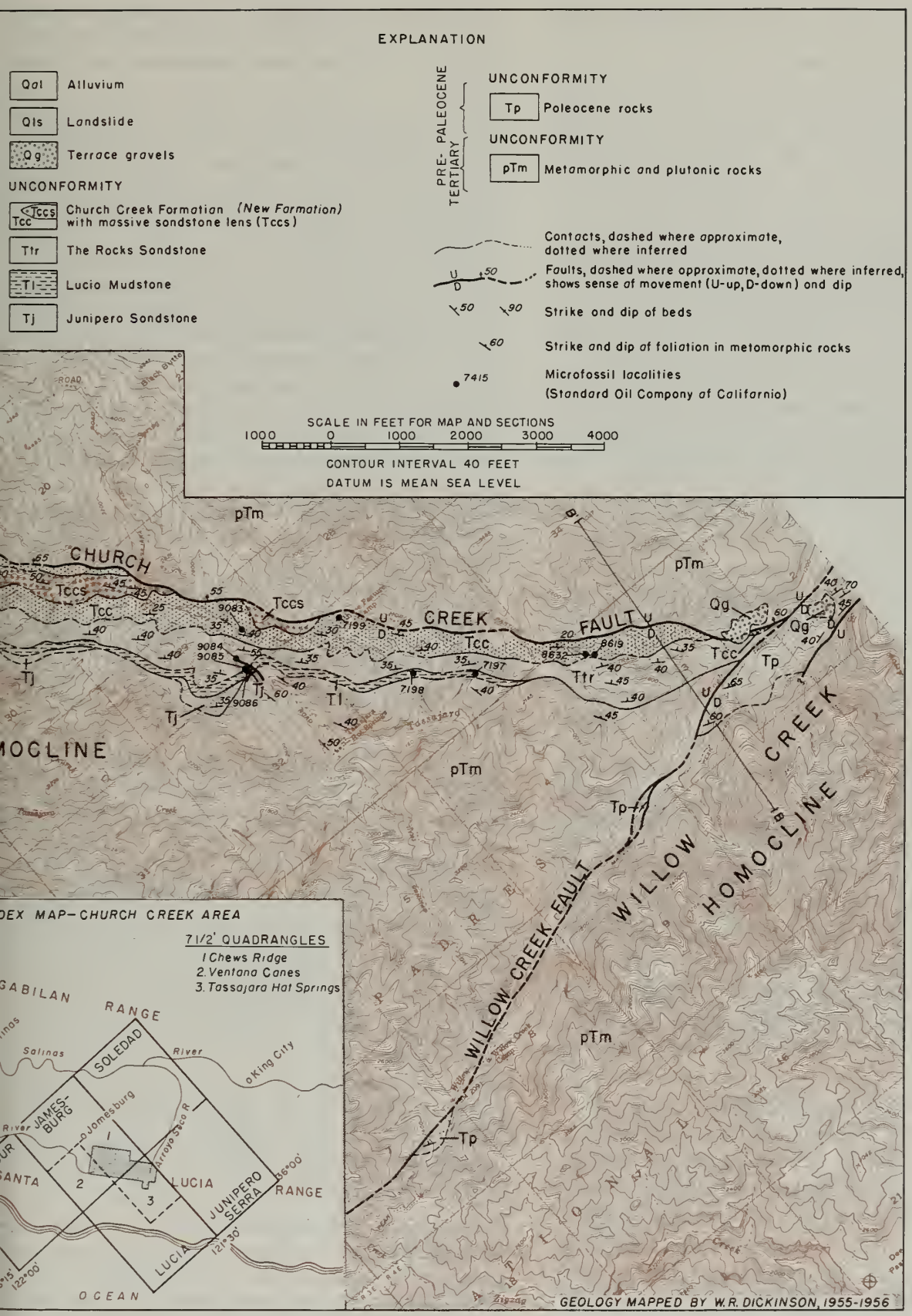

AGE
LITHOLOGY
SYMBOL AND THICKNESS
FORMATION AND DESCRIPTION
QUATERNARY
Qal, Qls, Qg
Alluvium, landslide, terroce, gravel.
TERTIARY
Oligocene (Refugian)
Eocene upper
middle
Paleocene
Tcc
1500'+
Church Creek Formation: thin-bedded sequence of intercalated gray and gray-green, silty mudstone; poorly-sorted, soft, brown, phosphotic and ferruginous siltstone that weathers white or tan; and fine-to medium-grained, calcareous, orkosic sandstone that weathers brown or tan: contains abundant Foraminifera of Refugian age above sandstone lens (Tccs) and Narizian age below sandstone lens.
Tccs
0'-600'
Tccs: lens of thick-bedded, medium-grained, calcareous, orkasic sandstone near middle of exposed sequence.
Local thin lentils of pebble and cobble conglomerate occur in lower part of formation.
Ttr
400-800'
The Rocks Sandstone: thick-bedded, fine-to coarse-grained, calcareous, orkosic sandstone; gray, weathers to buff; becomes coarser grained and thicker bedded toward east; thick basal conglomerate occurs in east where unit rests on metamorphic rocks; contains sparse Foraminifera.
Tl
0-250'
Lucia Mudstone: thin-bedded, green, calcareous, silty mudstone; contains abundant Foraminifera of Ulatisian age.
Tj 0-150'
Junipera Sandstone: thick-bedded, gray, pebbly, calcareous, orkosic sandstone; locally contains abundant orbitoid foraminfers.
Tp
750-1000'?
Paleocene rocks: chiefly dark gray to black, thin-bedded siltstone and silty mudstone with intercalated thin beds of gray, medium-grained, calcareous, orkasic sandstone; 100 feet of pebble and cobble conglomerate occurs near top of exposed sequence.
PRE-TERTIARY
pTm
Metamorphic rocks: (quartzite, schist, gneiss, marble, amphibalite), intruded by plutonic rocks, chiefly granitic.
(Vertical scale: 1 inch equals 500 feet.)

Figure 1. Columnar section, Church Creek area.

of the Monterey Formation is in the hills between Monterey Bay and Carmel Valley at the north end of the range (Blake, 1856). The type locality of the Vaqueros Formation is in the Vaqueros Creek-Reliz Canyon district on the eastern side of the range near Salinas Valley (Hamlin, 1904, p. 14). The work of Thorup (1942, 1943) in the latter district is fundamental to stratigraphic mapping in the Santa Lucia region. Thorup refined the stratigraphy of the several lithologic units which had formerly been grouped together as Vaqueros Formation and clarified the relationship of these strata to the rocks of the overlying Monterey Formation. In this revision, Thorup restricted the term Vaqueros Formation to an adequately defined sequence, and established five new Tertiary formations, four of which underlie the restricted Vaqueros Formation. Three of Thorup's sub-Vaqueros units—the marine Junipero Sandstone, Lucia Mudstone, and The Rocks Sandstone, all of Eocene age—are present in the Church Creek area. The place of the fourth—the continental Oligocene Berry Conglomerate—is occupied by equivalent marine beds of different lithology here assigned to the newly defined Church Creek Formation.

The distribution of Eocene strata in the northern Santa Lucia Range and surrounding districts was long

Figure 2. Geologic map and structure sections, Church Creek area, Monterey County, California.


EXPLANATION
Qal Alluvium
Qls Landslide
Qg Terrace gravels
UNCONFORMITY
Tcc Tccs Church Creek Formation (New Formation) with massive sandstone lens (Tccs)
Ttr The Rocks Sandstone
Tl Lucio Mudstone
Tj Junipero Sandstone
PRE-TERTIARY
UNCONFORMITY
Tp Paleocene rocks
UNCONFORMITY
pTm Metamorphic and plutonic rocks
Contacts, dashed where approximate, dotted where inferred
Faults, dashed where approximate, dotted where inferred, shows sense of movement (U-up, D-down) and dip
Strike and dip of beds
Strike and dip of foliation in metamorphic rocks
7415 Microfossil localities (Standard Oil Company of California)
SCALE IN FEET FOR MAP AND SECTIONS
1000 0 1000 2000 3000 4000
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
CHURCH CREEK FAULT
WILLOW CREEK FAULT
HOMOCLINE
pTm
Tccs
Tcc
Tj
Tl
Ttr
Tp
Qg
INDEX MAP—CHURCH CREEK AREA
7 1/2' QUADRANGLES
1 Chews Ridge
2 Ventana Canes
3 Tassajara Hot Springs
SANTA LUCIA RANGE
SOLEDAD
JAMESBURG
JUNIPERO SERRA
Salinas River
King City
Jamesburg
LUCIA
OCEAN
GEOLOGY MAPPED BY W.R. DICKINSON, 1955-1956

ago discussed by Herold (1936, p. 491-494), whose brief remarks foreshadowed and anticipated much of the information presented here.

Purpose and methods of study. Study of the Tertiary rocks exposed in the Church Creek area was undertaken (1) to clarify the age of the strata resting unconformably on the crystalline rock, (2) to test the westward continuity of the Tertiary formations established by Thorup (1942, 1943) on the eastern flank of the range, and (3) to investigate the lithology and stratigraphic relations of the beds on Church Creek mentioned by Schenck and Kleinpell (1936, p. 219) in their proposal of the Refugian Stage of the Pacific Coast Tertiary.

Field mapping was done on airphotos at a scale of approximately 1:20,000. Field data were transferred to 7½-minute (1:24,000) topographic quadrangle maps which became available during the period of field work. Approximately 30 thin sections were examined with the microscope.

Acknowledgements. This report is based largely upon a Master of Science thesis (Dickinson, Tertiary Stratigraphy and Structure west of the Arroyo Seco, Monterey County, California) submitted to Stanford University in 1956. Most of the field work was completed in 1955 and 1956 but was supplemented by brief visits in 1957 and 1958. A substantial part of the field expenses was borne by the R. H. Anderson Fund for Stratigraphy.

All of the foraminiferal assemblages collected were examined and identified in Oildale, California at the Western Operations, Inc., paleontology laboratory of the Standard Oil Company of California, by J. D. Bainton, E. J. Bolin, and E. H. Burtner to whom I am indebted. R. M. Kleinpell and Max Furrer have been kind enough to examine the faunal lists and to discuss the age significance of the faunas with me.

The advice and critical comments of S. W. Muller, R. R. Compton, and R. M. Kleinpell have contributed greatly to the progress of my study since its inception.

TERTIARY STRATIGRAPHY

Approximately 3250 feet of Paleocene, Eocene, and Oligocene (Refugian) strata crop out in three geographically separate homoclinal sequences within the Church Creek area. Each of the three sequences rests unconformably on structurally complex metamorphic rocks that are intruded locally by small bodies of granitic rock. The homoclines are adjacent to three major faults where the sedimentary rocks are in fault contact with the metamorphic rocks. The composite stratigraphic section includes the following rock units: undifferentiated Paleocene rocks, Junipero Sandstone, Lucia Mudstone, the Rocks Sandstone, and Church Creek Formation (new name). Structural evidence indicates that deposition was not continuous during the early Eocene and that Eocene strata were deposited unconformably on tilted and beveled Paleocene beds. The Eocene and Oligocene strata form a conformable sequence.

Miller Creek homocline. In Miller Canyon, approximately 1100 feet of Eocene strata are exposed along the southwest side of the Miller Creek fault. These rocks were discussed briefly as Eocene strata by Herold (1936), but were later mapped by Fiedler (1944) as Vaqueros-Temblor sandstone of early to middle Miocene age on the basis of poorly preserved megafossils thought by B. L. Clark to represent the Miocene "Vaqueros-Temblor transition zone" (Fiedler, 1944, p. 214 and 219). Foraminifera collected during the present study indicate that the strata are of middle and late Eocene age. Junipero Sandstone, Lucia Mudstone, and The Rocks Sandstone (Thorup, 1942, 1943) form the Miller Creek homocline.

Church Creek homocline. Along the southwest side of the Church Creek fault a maximum of 2250 feet of Eocene and Oligocene strata are exposed. The exposed thickness varies depending upon the amount of section faulted out locally along the Church Creek fault. Where these rocks crop out on Church Creek and in Pine Valley, they were mapped by Fiedler (1944) as Vaqueros-Temblor sandstone because of their lithologic similarity to the strata exposed in Miller Canyon. These same rocks had been mapped as "Church Creek beds" of Eo-Oligocene age by Reiche, who based the age assignment on a foraminiferal faunule collected by Herold (Reiche, 1937, p. 144). Herold (1936) had correlated this faunule with that of the Gaviota Formation, within which the type section of the Refugian Stage is located (Schenck and Kleinpell, 1936). Abundant Foraminifera collected during the present study indicate that the strata are of middle and late Eocene and early Oligocene (Refugian) age. Junipero Sandstone, Lucia Mudstone, The Rocks Sandstone, and Church Creek Formation (new name) have been recognized in the Church Creek homocline.

Willow Creek homocline. Approximately 1000 feet of undifferentiated Paleocene rocks are exposed along the south side of the Willow Creek fault on Willow Creek and in the banks of Arroyo Seco. Lacking fossil evidence, Reiche (1937, p. 146) thought these rocks were an upper part of his "Church Creek beds" of Eo-

Oligocene age. However, diagnostic megafossils and scanty microfossils indicate that the strata in the Willow Creek homocline are Paleocene.

Paleocene Rocks

The Paleocene strata exposed in the Willow Creek homocline along the south side of the Willow Creek fault are lithologically similar to rocks of the same age described by Compton (1957a) in the San Antonio River district to the southeast. The Paleocene rocks consist of dark gray and black silty mudstone and feldspar-rich siltstone, gray and white biotite-rich feldspathic and arkosic sandstone, and pebble and cobble conglomarate. Carbonaceous chips are abundant in the sandstone, and the characteristic dark color of the finer-grained beds is due to the presence of carbonaceous material. The strata are of marine origin.

The Willow Creek homocline is exposed in an elongate band extending from a point on the Willow Creek fault in the Lucia quadrangle one mile west of Arroyo Seco to a point two miles east of Arroyo Seco in the Junipero Serra quadrangle. Only the portion of the exposures west of Arroyo Seco are shown on the accompanying geologic map. The most continuous outcrops are in steep cut-banks along Arroyo Seco. In addition to the principal outcrops near Arroyo Seco, two small exposures of Paleocene rocks occur farther west at the mouth and head of Willow Creek.

The Paleocene sequence rests unconformably on the crystalline rocks. The unconformity is exposed along the south side of the elongate band of outcrops and is best observed at the extreme western end of the main exposures. On the north, the outcrops of Paleocene rocks are bounded by the Willow Creek fault. Approximately 750 feet of strata are present in the section exposed in the banks of Arroyo Seco. At Arroyo Seco a fault with undetermined displacement borders the outcrops of Paleocene rocks on the south, and the base of the sequence is not exposed. The total thickness exposed within the area may be as great as 1000 feet.

West of Arroyo Seco the Paleocene rocks are poorly exposed on slumped slopes with a deep soil cover. The sequence appears to be dominantly thin-bedded, dark gray, silty mudstone. Thin beds and lentils of gray and white sandstone are interspersed through the mudstone sequence. The basal fifty feet of the sequence, just above the unconformity, is composed of thick-bedded, medium- and coarse-grained sandstone with minor dark mudstone partings that grades upward to thin-bedded, medium-grained sandstone intercalated with dark gray, silty mudstone. Pebble conglomerate layers are contained in many of the coarse-grained sandstones in this basal sequence.

Because of minor local faulting at the south contact of the Paleocene rocks, basal sandstone beds do not appear in the outcrop along the banks of Arroyo Seco, where the following sequence is exposed:

(Bottom of section)

100 feet of sheored black mudstone adjacent ta the minor foult; intercalated thin sandstone beds ore fractured and disrupted.

150 feet of interbedded gray, medium-groined sandstone and block siltstone; within the sequence are a few massive sandstone beds 5 to 15 feet thick which cantoin thin loyers ond lenses of micoceous pebble conglomerate composed of granitic and metomorphic debris lithologicolly similar to the underlying rocks.

350 feet of thin-bedded black siltstone and silty mudstone contoining thin beds and lenses af fine- ta medium-groined gray sondstone.

100 feet of gray pebble and cobble conglomerate with a motrix of coarse-groined sandstone; grovel fraction includes chiefly quortzite ond granitic rock frogments, with minor omounts of metosedimentary schist and gneiss, amphibolite, and porphyritic ondesitic rock.

50 feet of interbedded dark siltstone ond medium-grained groy sandstone truncoted by Willow Creek foult.

(Top of section)

The sandstones of the Paleocene sequence are calcereous, micaceous, feldspathic arenites (Gilbert, 1955, p. 293) composed of nearly fresh subangular and subrounded grains of plutonic origin. Abundant biotite, a strongly pleochroic red-brown variety, forms as much as 6 percent of the sandstones.

Fossils and age. In 1955, members of the Stanford Geological Survey collected *Turritella pachecoensis* Stanton and *Cucullaea mathewsoni* Gabb, Paleocene index fossils, from contiguous exposures just outside the mapped area on the hillside east of Arroyo Seco. Identification was by A. M. Keen. It should be noted that Reiche (1937, p. 144) found *T. pachecoensis* in a boulder eroded from strata of similar lithology exposed to the south at Lost Valley in the Lucia quadrangle.

The following species of foraminifers were present in two microfossil samples, one collected in the banks of Arroyo Seco and the other from the hillside east of Arroyo Seco:

Silicosigmoilina californica Cushman & Church
Spiroplectammina gryzbowskii Frizzel
Bathysiphon aff. *B. eocenicus* Cushman & Hanna
Haplophragmoides aff. *H. trullissata* (Brady)
Cyclammina sp.
Trochammina (?) sp.

These species are long-ranging forms and are not conclusively diagnostic of Paleocene strata, but they are compatible with the Paleocene age indicated by the megafossils.

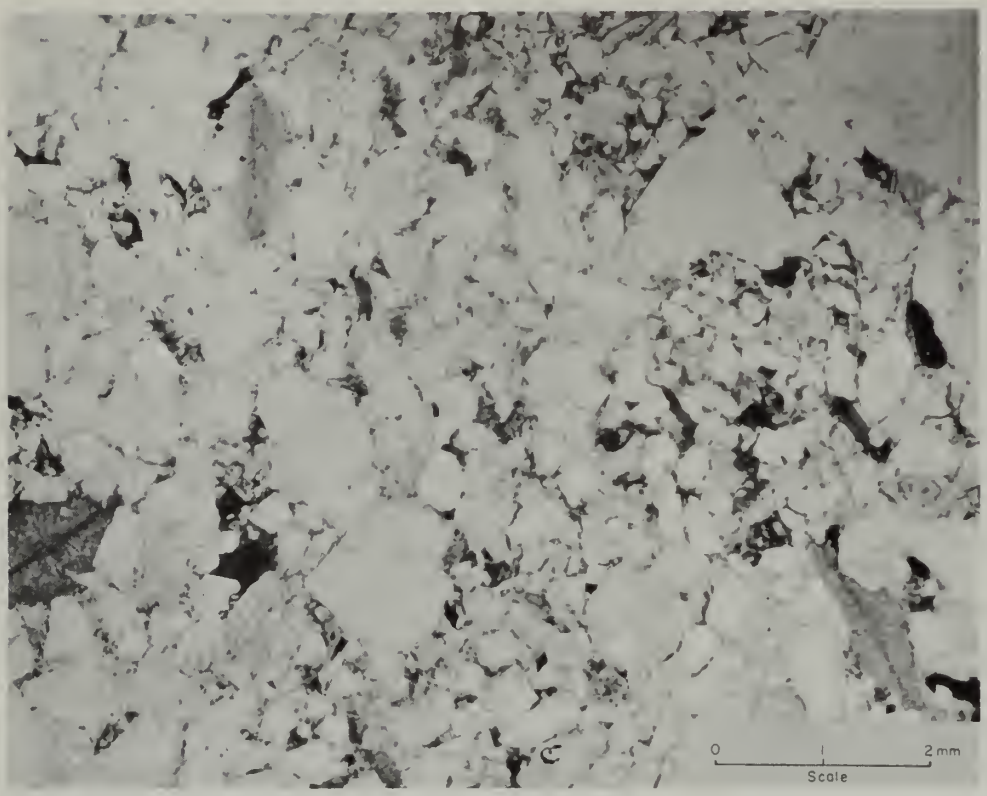


Photo 2. Thin section of typical Junipero Sandstone from upper valley of Church Creek. Note angularity of grains and presence of orbitoid Foraminifera. Plain light.

Junipero Sandstone

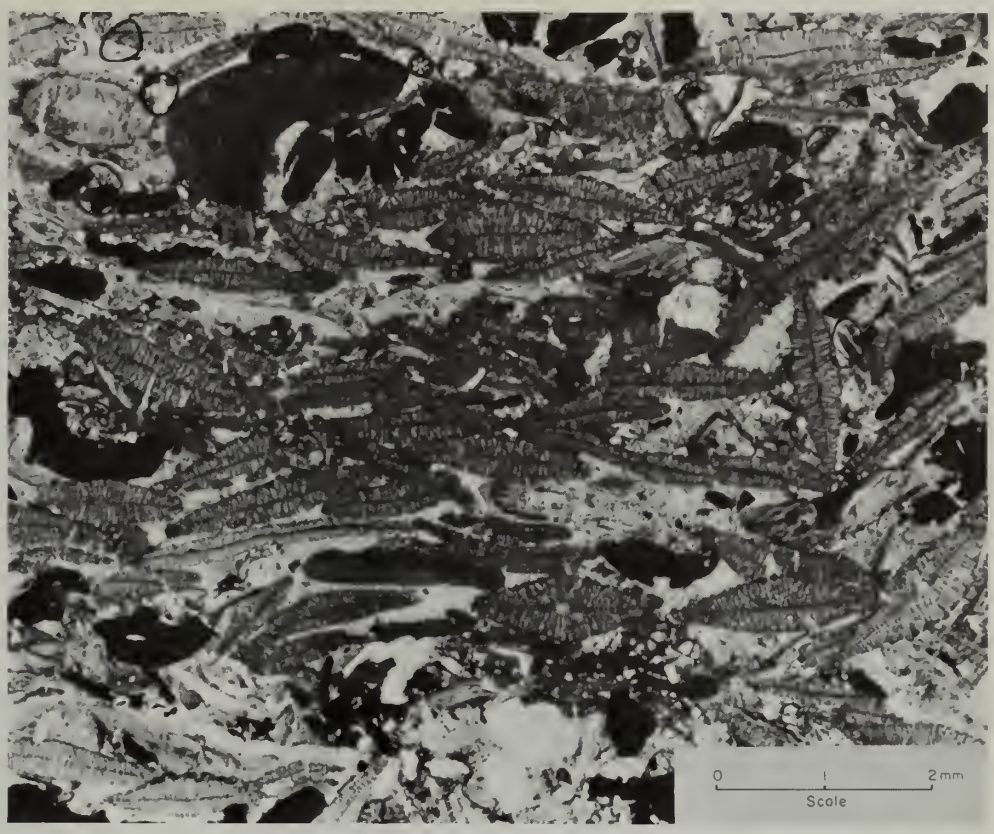
In the Church Creek and Miller Creek homoclines, and at the type locality in the Reliz Canyon area (Thorup, 1942, 1943), Junipero Sandstone is a thin, discontinuous sheet of light gray, coarse-grained to pebbly sandstone. It rests unconformably on metamorphic and associated granitic rocks, forming the base of the Tertiary sequence. The formation was deposited in shallow, agitated water as the sea inundated an irregular land surface. Overlying the Junipero Sandstone and in sharp contact with it is the Lucia Mudstone.

Junipero Sandstone is a resistant unit exposed on cliffed slopes along Miller Fork and as flatirons south of Pine Valley and Church Creek. The beds are massive or crossbedded and average 5 to 10 feet in thickness. Some outcrops are jagged with angular outlines controlled by joints; others have rounded shapes and gritty surfaces etched into relief by differential weathering of granules and pebbles. The strata consist dominantly of gray, coarse- to very coarse-grained sandstone. Scattered pebbles are common in most beds, and pebble layers and cross-bedded pebble conglomerate lenses occur near the base. Basal cobble or boulder conglomerate (0-8 feet) composed of rounded and angular blocks of metamorphic rock locally occupies small hollows on the underlying erosion surface. In Pine Valley, about 30 feet of well sorted, fine- to medium-grained sandstone in beds less than a foot thick occurs near the middle of the formation.

Junipero Sandstone reaches a maximum thickness of 150 feet in Pine Valley and Church Creek, and a maximum of 100 feet in Miller Canyon. Much thinner sequences (25 feet or less) are exposed discontinuously in scattered outcrops between Tassajara Road and The Caves on Church Creek. Local thickness variations are probably controlled by lows and highs on the underlying erosion surface.

The one outcrop in the canyon of Church Creek is a critical one, for it has yielded the only abundant identifiable fossils found within the formation in the Church Creek area. The rock exposed there is very calcareous sandstone and sandy bioclastic limestone. These tough rocks are composed of poorly sorted, micaceous, arkosic sand, rounded pebbles of granitic rock and schistose metamorphic rock, angular feldspar granules, algal debris, and orbitoid foraminifer tests in varying proportions (see photo 3). The composition of individual beds ranges from 75 percent terrigenous clastic debris to 85 percent fragmental calcareous debris, dominantly orbitoid tests. Beds average 2 feet thick and are locally fluted parallel to the bedding by solution weathering.

The typical rock type of Junipero Sandstone is arkosic arenite (Gilbert, 1955, p. 293) cemented by abundant carbonate (see photo 2). The terrigenous material is composed entirely of unweathered, sub-



Phota 3. Thin section af sandy limestone from the Junipero Sandstone eost of The Coves in Church Creek canyon. Nate the arbitoid foraminifers and algal debris (the block elliptical autlines are air bubbles in the thin section). Plain light.

angular grains derived locally from rock types common in the underlying metamorphic and granitic terrane. Although the sand grains of the framework are not well sorted, fine-grained detrital matrix is neglible. Quartz and feldspar grains, granitic and quartzitic rock fragments, strongly pleochroic red-brown biotite flakes (1–5%), and abundant heavy minerals are the only terrigenous clastic constituents. The ratio of quartz to feldspar varies from 2:1 to 1:1, and is most often nearer the latter. The ratio of potash feldspar to plagioclase varies from 2:1 to 4:1. The cement is chiefly clear anhedral calcite, portions of which appear to have been derived from the recrystallization of fossil fragments. Some cement is turbid from minor amounts of original detrital matrix and some contains dolomite (?) rhombs. Scattered tests of orbitoid foraminifers, though they form only a small proportion of the rock, are consistently present; other fossil material is not identifiable. Some clastic grains, notably those of plagioclase, are partly replaced by calcite cement.

Fossils and age. The only fossils found in Junipero Sandstone are algal remains of *Lithothamnium* (?) sp. and the orbitoid foraminifers *Discocylina (Aktinocyclina) aster* Woodring and *Pseudophragmina (Proporcyclina) psila* (Woodring). The presence of "reefoid" algae and benthonic orbitoids is probably indicative of shallow, aerated waters during deposition. One occurrence very similar to that in the Church Creek area has been reported by Reed (1936) from Alamo Canyon in Santa Barbara County, where bioclastic limestone grades laterally into the basal calcareous conglomerate of a Tertiary sequence. Disococyclines are common in middle Eocene sandstones of California; most occurrences are in the "Capay" portion of the California Eocene (Watson, 1942). They are typical of the B group of foraminiferal zones of Laiming (1940). Mallory (1959, p. 35–36) reports that *P. psila* and *D. aster* are common forms in the upper part of his Penutian Stage. As overlying Lucia Mudstone strata are probably of early Ulatisian age, the tentative assignment of Junipero Sandstone to the late Penutian seems reasonable.

Lucia Mudstone

At the type locality in the Reliz Canyon area (Thorup, 1942, 1943), Lucia Mudstone consists of 300 to 500 feet of thin-bedded greenish-gray to steel-gray mudstone with some maroon mudstone in the upper part. Because the rocks of the formation at the type locality and in the Church Creek area display no fissility, the formation is herein called Lucia Mudstone, rather than Lucia shale as originally named. Except that it is thinner (0–250 ft.), Lucia Mudstone of the Church Creek area closely resembles strata of the type locality. Deposition of Lucia Mudstone completed burial of the erosion surface cut on metamorphic

rocks in most parts of the Church Creek area. Except in the southeast and northwest parts of the area, Lucia Mudstone was deposited as a continuous, thin (150–250 feet) blanket of poorly-sorted, marine muds, probably in quiet waters.

Lucia Mudstone weathers readily and is easily eroded; most exposures are largely masked by soil on bushy slopes or grassy flats. The dominant rock type is poorly-sorted, gray-green, calcareous mudstone with characteristic spheroidal ("nodular") fracture. Individual beds are poorly defined and 1 inch to 2 inches thick. Bedding is shown in thin section by a crude and irregular layering of lenticular bands unusually rich in silt with bands rich in clay. Bedding is also reflected by the preferred orientation of biotite flakes, elongate fossil fragments and quartz grains, and stringers of ferrunginous material. Typical rocks contain 35 percent to 65 percent angular, feldspathic silt set in a murky matrix of clay minerals and finely crystalline calcite. Green biotite is abundant, comprising as much as 10 percent of the rocks, and probably accounts for the green color of the rock. Pelagic foraminifers are so abundant locally that more than 25 may appear in a single thin section. Some sequences of dark gray or blue-gray mudstone contain authigenic pyrite, perhaps formed in locally stagnant waters in pockets on the erosion surface that had not been completely filled by deposition of Junipero Sandstone. Near Church Creek Divide, a few thin sequences of maroon mudstone beds occur in the upper part of the formation, and three fine- to medium-grained arkosic sandstone beds, each 2 to 5 feet thick, are present near the middle of the formation.

Lucia Mudstone rests comformably on Junipero Sandstone and unconformably on metamorphic rock where Junipero Sandstone was not deposited. No basal standstone was seen. The contact with Junipero Standstone is sharp, except in the upper valley of Church Creek, where the contact is gradational and marked by 25 feet of interbedded medium-grained sandstone and green mudstone. These beds are 3 to 6 inches thick and are mapped as basal Lucia Mudstone. Lucia Mudstone is overlain conformably by The Rocks Sandstone. The upper contact of Lucia Mudstone is everywhere gradational and marked by 10 to 30 feet of interbedded fine-grained, micaceous, arkosic sandstone and green, silty mudstone. The contact is placed at the top of the interbedded sequence beneath the lowest bed of massive buff sandstone in a sequence composed dominantly of sandstone. Some of the thin sandstone beds in the interbedded sequence at the contact are cross-bedded, the cross-laminations being defined by layers rich in biotite.

Lateral variations. In the western and central parts of the mapped area, the Lucia Mudstone is of the same lithology as at the type locality. However, in the southeastern part of the area, the formation consists of two parts, only the upper of which has the typical lithology dominant to the northwest. In roadcuts along Tassajara Road, the lower part of the formation consists of thin-bedded, poorly sorted, green and tan siltstone in ½- to 2-inch beds intercalated at intervals of 3 inches to 3 feet with 1-inch to 1-foot beds of fine- to medium-grained, calcareous sandstone. Some of the sandstone beds contain green mudstone chips in their upper portions. The two parts of the formation can be recognized still farther southeast in the canyon that drains Horse Pasture. There the upper green mudstone sequence contains at least two massive buff sandstone beds, each 4 to 5 feet thick, that are of the same lithology as the overlying The Rocks Sandstone. In the next small canyon to the southeast, the lower member is nearly absent and the remaining upper member has changed markedly in character. The entire formation is much thinner here and consists almost entirely of interbedded silty, green mudstone layers 2 to 10 inches thick interbedded with silty, fine-grained, buff sandstone beds 2 to 6 inches thick. Widely spaced, massive, medium-grained, buff sandstone beds similar in lithology to the overlying The Rocks Sandstone occur in beds as much as 10 feet in thickness. Still farther to the east, the Lucia Mudstone pinches out as a result of the combined progressive overlap and lateral gradation.

Fossils and age. No megafossils were found in the Lucia Mudstone, although burrows filled with sand or silt are common.

Abundant foraminifers were collected from 19 different localities. In all, approximately 60 foraminiferal species were present in the collections. The assemblage is dominantly pelagic; the genera *Globigerina* and *Globorotalia* are by far the most abundant, suggesting that free connection with the open ocean existed. The following are the species which appeared most frequently in the collections.*

Amphimorphina ignota Cushman & Siegfus
Anomalina dorri Cole var. *aragonensis* Nuttall
Asterigerina crassaformis Cushman & Siegfus
Cibicides perlucida Nuttall
Dorothia principiensis Cushman & Bermudez
Globigerina bulloides d'Orbigny
Globigerina triloculinoides Plummer
Globorotalia aragonensis Nuttall
Parrella tenuicarinata (Cushman & Siegfus)
Robulus inornatus (d'Orbigny)
Tritaxilina colei Cushman & Siegfus

* Also see microfossil check list in Appendix.

Photo 4. Outcrop of The Racks Sandstone near The Caves on Church Creek. The beds shown are 3 to 12 feet thick.

These forms are characteristic of a faunal group reported by Laiming (1940) as present in his C zone and recurrent in his A-2 zone.

Mallory (1959, p. 53) has assigned a faunule from the upper Lucia Mudstone in the type locality to his Ulatisian Stage of the middle Eocene. However, according to Wardle (1957, p. 19–24), the bulk of the Lucia Mudstone at the type locality belongs to the underlying Penutian Stage. Comparison of faunal lists from the Church Creek area with faunal lists given by Mallory suggests that Lucia Mudstone strata exposed there are referrable in their entirety to the Ulatisian Stage, and probably to the lower or *Vaginulinopsis mexicana* Zone (Mallory, 1959, p. 42–43). If these indicated age relationships are valid, it would appear that the progressive marine inundation of the Santa Lucia region that is recorded by the Junipero-Lucia interval proceeded from east to west in the latitude of Arroyo Seco—that is, from the vicinity of present Salinas Valley westward toward the ocean.

The Rocks Sandstone

At the type locality in the Reliz Canyon area (Thorup, 1942, 1943), The Rocks Sandstone consists of 1500 feet or more of thick-bedded, nonfossiliferous, massive, tan or buff sandstone that overlies the Lucia Mudstone conformably and is overlain disconformably by the continental Berry Conglomerate. In the Church Creek area, The Rocks Sandstone is lithologically similar to the type strata and occupies the same stratigraphic position above the Lucia Mudstone, but the unit is thinner and is overlain conformably by the marine Church Creek Formation. Moreover, The Rocks Sandstone onlaps the Lucia Mudstone to rest unconformably on metamorphic rock in the northwestern and southeastern parts of the Church Creek area.

The Rocks Sandstone is composed of massive, thick beds that crop out as ledged cliffs or steep slopes, prominent hogbacks and bare flatirons. Individual beds range from 2 to 15 feet in thickness, averaging 3 to 6

feet, and are separated by thin, gray or green, silty mudstone layers. The unit is homogeneous, being composed of moderately sorted, fine- to medium-grained sandstone. It is tan or gray and well indurated in rare fresh outcrops, but characteristically pale buff and friable in the rounded natural outcrops. The rock is commonly cemented by calcite and contains large, bulbous, dolomitic (?) concretions that weather to a dark brown color. Cavernous weathering is characteristic, as at The Caves.

The sandstones of the formation are arkosic arenites (Gilbert, 1955, p. 293) composed of subangular grains. Most beds contain abundant calcareous cement but others, particularly in the southeast, have almost no cement and are bound together by the sutured interpenetration of clastic grain margins, a texture presumably caused by pressure solution. The ratio of quartz to feldspar is most commonly near 1:1 and does not exceed 3:2. The ratio of potash feldspar to plagioclase varies from 3:1 to 5:1. Fine-grained lithic fragments, chiefly aphanitic volcanic rocks, are present in amounts ranging from 5 to 10 percent. The percentage of mica ranges from less than one to two. Feldspars, micas, and rock fragments in The Rocks sandstone are commonly weathered.

The Rocks Sandstone is about 800 feet thick in the western part of the area, but thins to only 400 feet at the Willow Creek fault in the southeastern part of the area. The thinning represents a gradation from a relatively offshore site of deposition, perhaps similar to that of the Lucia Mudstone, to a nearshore site of strongly agitated marine waters. The thinning takes place southeast of Tassajara Road and is accompanied by coarsening of grain size, thickening of beds, and thinning of mudstone partings. At Horse Pasture, medium- to coarse-grained sandstone beds first appear in the unit. Scattered pebbles of granitic rock, quartzite, and dark, porphyro-aphanitic volcanic rocks occur in the coarser beds.

Near the Willow Creek fault, the formation is dominantly medium- to coarse-grained sandstone in massive beds ranging from 6 to 12 feet in thickness. Layers and cross-bedded lenses of pebble conglomerate are common within individual beds. At the base of this portion of the unit is 100 feet of pebble and cobble conglomerate resting unconformably on metamorphic rock. The pebbles and cobbles are composed of granitic rock, porphyro-aphanitic volcanic rock, quartzite, amphibolite, schist, and gneiss. These beds average 10 feet in thickness. At the top of the conglomerate sequence is a 4-foot thick layer of sedimentary breccia that contains angular blocks of crystalline rock.

Fossils and age. Orbitoid foraminifers similar to those found in Junipero Sandstone occur in the conglomeratic portion of The Rocks Sandstone near the Willow Creek fault. The only specimens found were in the lower 200 feet of the unit. It is conceivable, therefore, that what has been mapped as the lower part of The Rocks Sandstone resting unconformably on crystalline rocks near the Willow Creek fault is laterally equivalent to the beds mapped elsewhere as Junipero Sandstone. Lucia Mudstone, which normally serves to separate and delimit the two sandstone units, is absent near the Willow Creek fault, having in part graded laterally into and in part been onlapped by The Rocks Sandstone. The field relationships between Lucia Mudstone and The Rocks Sandstone indicate that the conglomeratic basal sequence of The Rocks Sandstone is younger than Junipero Sandstone exposed to the northwest. Consequently, the occurrence of a sparse orbitoid faunule in basal The Rocks Sandstone near the Willow Creek fault is interpreted as a facies recurrence in deposits formed in shallow, agitated waters, rather than evidence of age equivalence with Junipero Sandstone to the northwest.

From exposures in a road cut along Tassajara Road, the following foraminiferal faunule was collected from a mudstone bed between massive sandstone beds of The Rocks Sandstone: *Cibicides perlucida* Nuttall, *Globigerina triloculinoides* Plummer, *Globorotalia aragonensis* Nuttall, and *Tritaxilina colei* Cushman & Siegfus. All four species are common in the underlying Lucia Mudstone of middle Eocene age and, with one exception, also occur in the pre-Refugian lower portion of the overlying Church Creek Formation. Judging from its stratigraphic position, The Rocks Sandstone is of middle to late Eocene age, perhaps representing parts of the Ulatisian and Narizian Stages of Mallory (1959).

Church Creek Formation

The name Church Creek Formation is used here to designate the marine sequence of interbedded gray mudstone, soft brown siltstone, and brown and gray sandstone conformably overlying The Rocks Sandstone near The Caves on Church Creek. The exposures in the valley of Church Creek in W½ sec. 13, T. 19 S., R. 3 E., are designated as the type locality of Church Creek Formation. At the type locality, the base of the formation is placed at the top of the massive sandstone bed exposed beside the Church Creek trail at fossil locality 7475. The type section is taken as the sequence exposed along the sides of the small draw leading north from this point past fossil localities 7414 and 7470. The top of the section is

terminated by the Church Creek fault. About 800 feet of strata are exposed in the type locality.

The name "Church Creek Formation" should be clearly distinguished from the informal name "Church Creek beds" employed by Reiche (1937) to embrace all of the Tertiary units exposed in the Church Creek area, including the Paleocene rocks, Junipero Sandstone, Lucia Mudstone, and The Rocks Sandstone, as well as the Church Creek Formation. However, the microfossil faunule which Reiche used to characterize the age of his "Church Creek beds" was collected by Herold from exposures of restricted Church Creek Formation, as here defined, on Church Creek (Reiche, 1937, p. 144).

The Church Creek Formation is a heterogeneous unit composed of alternations of several clastic marine rock types, which are mostly thin-bedded and unresistant. Lateral variations in lithology are great, but are largely obscured by poor exposures covered by thick soil underlying gentle grassy slopes. Most outcrops are small and located in shallow gullies. The most typical rock types are drab gray or gray-green silty mudstone; poorly-sorted, soft, brown siltstone that weathers to white or tan; and fine- to medium-grained, calcareous, arkosic sandstone that weathers to brown or tan. Lenticular pebble and cobble conglomerate beds from three to eight feet in thickness occur locally. A thick lens of massive, resistant, gray, arkosic sandstone occurs within the formation near Tassajara Road.

The lower conformable contact with The Rocks Sandstone is gradational in most places. It is placed on top of the highest bed of massive buff sandstone in a sequence composed dominantly of sandstone. The maximum exposed thickness is about 1,250 feet in the Church Creek homocline due southwest of Black Butte. However, the composite thickness of the formation probably exceeds 1,500 feet.

Lithology and lateral variations. At the type locality near The Caves, the lowermost 250 feet of the Church Creek Formation is thin-bedded, foraminiferal, gray, silty mudstone with spheroidal ("nodular") fracture. The rocks contain tiny authigenic pyrite cubes and large carbonate concretions that weather to tan or orange. Intercalated at wide intervals in the mudstone sequence are thin beds of massive, ferruginous, medium-grained, brown sandstone and flaggy, fine-grained, gray sandstone. Above the lower mudstone sequence, the Church Creek Formation is composed dominantly of thin-bedded, poorly sorted, brown, ferruginous and phosphatic siltstones that weather to orange or tan. Thin beds of medium- and fine-grained, flaggy, gray, arkosic sandstone are intercalated at varying intervals in the siltstone sequence. The sandstone beds contain scattered, rounded glauconite grains and rounded granules of quartz and feldspar.

Westward, between Church Creek Divide and Pine Valley, where only the lower part of the Church Creek Formation is exposed, the basal gray mudstone sequence is absent. The lower 200 feet of the formation consists of interbedded gray mudstone; poorly-sorted, laminated, brown siltstone; very fine-grained, soft, white, feldspathic sandstone; and well-indurated, medium-grained, brown, arkosic sandstone. The brown sandstone beds, whose cement is calcareous and ferruginous, are resistant and stand out on steep grassy slopes as dark brown ribs 1 foot to 4 feet thick and spaced at intervals of 10 to 25 feet. Immediately southeast of the type locality near The Caves, the lowest 100 feet of the formation is dominantly thin-bedded, tan siltstone containing intercalated ferruginous, brown sandstone in beds similar to those near Church Creek Divide. Above these beds is a sequence of gray mudstone similar to that which extends to the base of the formation near The Caves.

Toward the southeast, near Tassajara Road, a thick lens of massive sandstone interfingers westward between the basal brown siltstones and the overlying gray mudstones. From its feather edge, the lens thickens to 600 feet within a mile along the strike (see figure 3). The sand may have been worked westward by marine currents from the district to the east where the partly correlative Berry Conglomerate was being deposited in a continental environment. The massive sandstone consists of poorly sorted, medium-grained, gray, arkosic sandstone composed of subangular grains and containing scattered pebbles. Beds range from 2 to 12 feet in thickness and are commonly graded, especially in their upper portions.

Near Tassajara Road, the Church Creek Formation sequence beneath the massive sandstone lens is approximately 400 feet thick. The basal 200 feet of the formation is a thin-bedded sequence of silty, gray and gray-green mudstone containing widely-spaced thin beds of fine-grained, micaceous sandstone. The overlying 200 feet of strata beneath the sandstone lens is a sequence of thin-bedded, brown, sandy siltstone containing numerous thin beds of fine-grained, buff sandstone. Near Horse Pasture, the exposed sequence of lower Church Creek Formation is thin-bedded, tan siltstone with intercalated beds of brown sandstone. This lower sequence grades upward to interbedded micaceous, green mudstone and buff siltstone containing intercalated beds of very fine-grained, gray, micaceous sandstone.

Petrography. Gray mudstone of the type common in the lower Church Creek Formation at the type locality, is a poorly sorted, calcareous rock rich in finely comminuted, dark organic matter. The rock is dominantly silty mudstone containing approximately 50 percent feldspathic silt, but microscopic lenses of siltstone aligned parallel to bedding occur within the mudstone. Biotite is not conspicuous.

The massive, brown and tan siltstones so common in the Church Creek Formation are poorly sorted rocks whose grain size ranges from clay-sized material to fine sand, but in which silt is the dominant grain size. The rocks are rich in ferruginous matter that is dispersed within the clay fraction and imparts the brown color to the rock. Abundant phosphatic material occurs in impure ovoid pellets as large as sand grains and in thin, irregular bands. Clay-size material, ferruginous matter, and phosphatic lenses form a heterogeneous matrix surrounding the silt particles and rare sand grains. The silt grains are dominantly feldspar and quartz.

The typical gray, brown, and tan sandstones of the formation are arkosic arenites (Gilbert, 1955, p. 293) composed of subangular grains. The cement is dominantly calcareous, but ferruginous matter is present interstitially in varying proportions and commonly imparts a brown color to the rock. The carbonate cement may be in part dolomitic. The ratio of quartz to feldspar ranges from 1:1 to 3:2. The ratio of potash feldspar to plagioclase varies from 4:1 to 6:1, or greater in isolated instances. Mica is present in amounts of 1 to 3 percent. Fine-grained rock fragments, chiefly aphanitic volcanic rocks, comprise approximately 5 percent of the sandstones.

The sandstone of the massive lens near Tassajara Road is pebbly, gray, arkosic arenite (Gilbert, 1955, p. 293) with calcareous cement. Unstable, fine-grained rock fragments, chiefly aphanitic volcanic rock, comprise approximately 10 percent of the sandstone. Mica is present in amounts of 1 to 2 percent. The ratio of quartz to feldspar is near 1:1 but locally is smaller.

Fossils and age. No megafossils were found in the Church Creek Formation but abundant foraminifers were collected from 10 different localities. Approximately 60 foraminiferal species were present in the collections, which represent two distinct faunules.*

Comparison of faunal lists from the type locality on Church Creek near The Caves with those given by Schenck and Kleinpell (1936), Kleinpell (1938), and Mallory (1959) suggests that type Church Creek Formation belongs to the Refugian Stage. The base of the formation and the base of the stage are probably nearly coincident there. No strata younger or older than Refugian are known to be present in the type locality. The faunule from the type locality is the one sampled earlier by Herold (1936) to which Reiche (1937, p. 144) makes reference. It is characterized by the following forms:

Bulimina ovata d'Orbigny
Bulimina sculptilis Cushman
Haplophragmoides trullissata (Brady)
Plectofrondicularia packardi Cushman & Schenck
Uvigerina gallowayi Cushman

To the east, foraminiferal collections along Tassajara Road and in the vicinity of Horse Pasture reveal the presence of a second faunule and indicate that upper Eocene strata, presumably of the Narizian Stage (Mallory, 1959), are present in the lower Church Creek Formation beneath the prominent massive sandstone lens which crops out near Tassajara Road. No Refugian collections were found beneath this lens.

The faunal relationships thus suggest that the lithologic contact between The Rocks Sandstone and Church Creek Formation descends, in a time-stratigraphic sense, toward the east, and that the massive sandstone lens within Church Creek Formation near Tassajara Road is approximately correlative with the base of the formation at the type locality near The Caves. Hence, lower Church Creek Formation near Willow Creek in the east is laterally equivalent in age to upper The Rocks Sandstone near The Caves in the west.

The stratigraphic position and microfossil content of the Church Creek Formation suggest that it must be correlative, at least in part, with the following lithologic units in the surrounding region: (a) the San Lorenzo Formation, and possibly some upper part of the Butano Sandstone, in the Santa Cruz Range (Branner, Newsome, and Arnold, 1909); (b) the San Juan Bautista Formation, and possibly some part of the Pinecate Formation, in the northern Gabilan Range (Kerr and Schenck, 1925; Allen, 1946); (c) the Continental Berry Conglomerate, and possibly some upper part of The Rocks Sandstone, in the Reliz Canyon area bordering Salinas Valley (Thorup, 1943); and (d) a marine mudstone sequence, lying conformably beneath restricted Vaqueros Formation near The Indians Ranch and the headwaters of Arroyo Seco, from which assemblages of Refugian foraminifers were collected by members of the Stanford Geological Survey in 1958. The last-named mudstones, containing Refugian faunules and presumbaly correlative with the Church Creek Formation, crop out only 10 or 12 miles southeast of the localities on Church Creek and con-

* Also see microfossil check list.

Phata 5. Church Creek and Willow Creek faults, viewed taward narthwest. The Willow Creek fault follaws the easterly caurse of lawer Tassajara Creek (diagonally fram far left ta lawer right) and farms north baundary af Paleacene rocks (waaded foreground). The Church Creek fault trends narthwest acrass law, brushy, spurs (right center) flanking the steep ridge at the right. The Racks Sandstone farms praminent flatirons (center) that dip nartheast inta the Church Creek fault. The twa faults intersect at Tassajara Creek near the sparsely waoded flat (lawer right center).

stitute the only other marine Refugian exposures discovered in the Santa Lucia Range to date.

STRUCTURAL GEOLOGY

The lower Tertiary sedimentary rocks are exposed in three long, narrow homoclines, each of which is bordered along its downdip margin by a major fault which closely parallels the strike of that homocline. Along the three faults, the Tertiary rocks abut pre-Tertiary metamorphic and plutonic igneous rocks. The three homoclinal sequences of Tertiary rocks rest unconformably upon similar crystalline rocks. Unconformable contacts between sedimentary and crystalline rocks are exposed along the updip margins of the homoclinal exposures.

The Church Creek and Miller Creek homoclines are parallel bands of Eocene and Oligocene strata which strike northwest and dip 20°–50° NE. These two homoclines are bordered along their northeastern margins by two parallel reverse faults—Church Creek and Miller Creek faults. Both faults dip 50°–80° NE (average 60°–65°). The Willow Creek homocline lies south of the other two and is composed of Paleocene rocks. Its strike is nearly east-west and it dips 30°–70° N. The Willow Creek homocline is bordered along its northern margin by the vertical Willow Creek fault.

Reverse Faults

The attitudes of the Miller Creek and Church Creek faults were established by the solution of three-point problems posed in places where the traces cross adjacent noses and draws, and by direct sightings across canyons. The sense of displacement is reverse, as is evident from the map and cross-sections. The fault zones are well exposed only along Tassajara Road. Miller Creek fault dips about 60° NE in the roadcuts,

and the contact between mudstone and crystalline rock at the fault is a planar zone of gouge approximately 6 inches thick. The gouge adjacent to crystalline rock is black and that adjacent to sedimentary rock is reddish brown. The mudstone is mildly sheared for a distance of 5 feet from the fault plane. On the other side of the contact, in the crystalline rock, a dozen or more anastomosing gouge zones, each 1 inch or less in thickness, are present within a zone 20 feet thick. The five gouge zones nearest the fault contact are essentially planar and parallel to the contact; those farther from the contact have variable dips. In roadcuts, the Church Creek fault contact is also a thin zone of black gouge, a foot or less in thickness, which separates crystalline rock from siltstone. Parallel sheared bands and stringers of gouge occur in the crystalline rock adjacent to the fault contact for various distances not exceeding 100 feet.

The youngest rock offset by Church Creek and Miller Creek faults is of Refugian age. However, the two faults are members of a northwesterly trending reverse fault system which regionally involves much younger rock. Miocene strata of varying ages are offset by several similar faults to the north (Fiedler, 1944; Trask, 1926) and upper Miocene beds are exposed in the foot wall of the Sur Hill fault to the west (Trask, 1926). By analogy, it is reasonable to conclude that the time of major displacement on the Church Creek and Miller Creek faults was Pliocene or later. The position of the sedimentary rock in the deeply eroded core of the Santa Lucia Range suggests that all strata younger than Refugian age have been eroded from the vicinity.

The amounts of displacement of the Miller Creek and Church Creek faults cannot be accurately assessed, for no Tertiary sedimentary rocks crop out on the northern sides of the fault zones anywhere along their courses. However, displacements are certainly great. Old erosion surfaces on the crystalline rocks beneath Eocene strata south of the Miller Creek and Church Creek faults must extend 2000 to 4000 feet lower in elevation than outcrops of crystalline rock on the ridge crests immediately to the north of each of the faults. The dominant movement on the faults appears to be dip slip; therefore, the two faults have minimum displacements of half a mile to a mile.

Relationship to folds. The parallelism in strike of the Church Creek and Miller Creek faults to adjacent homoclines of sedimentary strata strongly suggests that reverse faulting was genetically related to folding. This same geometric relationship exists throughout the northern Santa Lucia Range where reverse faults commonly strike parallel to adjacent downfaulted homoclines or synclines of sedimentary rocks (see maps of Trask, 1926; Reiche, 1937; Fiedler, 1944). Compton (1960b) has shown that similar reverse faults, which lie along structural strike to the southeast, typically dip toward anticlines and break fold limbs.

Willow Creek Fault

Willow Creek fault is a vertical zone of sheared metamorphic and sedimentary rocks as much as 100 feet thick. Thin black gouge bands in the crushed rocks within and near the fault zone are also vertical. The history of displacement along the zone has been long and complex, but can be resolved into two principal periods of movement. As shown on figure 3, the contrasting stratigraphic sequences of Blocks A and B indicate early Eocene displacement with the south side downthrown at least 1000 feet with respect to the north side. Subsequent erosion removed the Paleocene strata from the north side of the fault, but they were preserved on the downthrown southern block. During the subsequent transgression of the Eocene sea, middle and upper Eocene strata were deposited directly on metamorphic rocks north of the fault and presumably on Paleocene strata south of the fault, although erosion has removed all trace of Eocene strata from Block A.

A much later time of movement is indicated by the termination of the Plio-Pleistocene Church Creek reverse fault at the Willow Creek fault. During this second period of movement, the Willow Creek fault

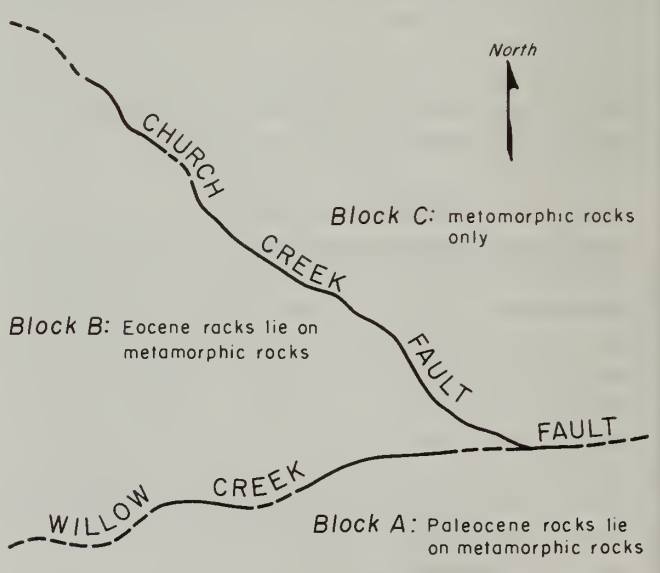


Figure 3. Diagrammatic map of Church Creek and Willow Creek faults.

acted as an oblique-slip tear fault transverse to the Church Creek reverse fault; that is, Block C of figure 4 moved up and to the west with respect to Blocks A and B. The juxtaposition of Paleocene beds of Block A, and Eocene beds of Block B suggests that Block A moved up slightly with respect to Block B. During this second period of movement, the relative displacement of Blocks A and B was of the order of several hundreds of feet, but the relative displacement of Blocks A and C, and Blocks B and C was of the order of several thousands of feet.

GEOLOGIC HISTORY

The history of Tertiary sedimentation and diastrophism in the Church Creek area can be summarized as follows:

(1) At least 1000 feet of marine Paleocene strata, mainly sandstone and dark mudstone, were deposited on an erosion surface cut on metamorphic rock.

(2) In early Eocene time, movement on the Willow Creek fault was followed by erosion that entirely stripped the Paleocene strata from the north side of the fault, although they were preserved on the downthrown southern side.

(3) Renewed subsidence began in the middle Eocene and continued at least into the Oligocene, as an aggregate thickness of nearly 2500 feet of marine strata belonging to the Junipero Sandstone, Lucia Mudstone, The Rocks Sandstone, and Church Creek Formation were deposited on the erosion surface cut during the early Eocene.

(4) There is no record of the Miocene within the area, but the presence of strata of the Monterey and related formations to the east, north, and west (Schombel, 1943; Fiedler, 1944; Trask, 1926) suggests that Miocene beds may have once been present within the area before it was uplifted and deeply eroded in the late Cenozoic.

(5) In common with other areas of the northern Santa Lucia Range, Plio-Pleistocene folding, reverse faulting, and uplift, with ensuing erosion, constituted the principal diastrophism of the Cenozoic Era. The Miller Creek and Church Creek faults and homoclines formed at this time and the Willow Creek fault was reactivated as an oblique-slip tear fault transverse to Church Creek reverse fault.

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(Continued on page 44)

APPENDIX

FORAMINIFERA FROM LUCIA MUDSTONE

Church Creek Area, Monterey County, California

	Standard Oil Co. of California Western Operations, Inc. Paleontology Laboratory Locality Numbers	S.O. 9064	S.O. 9063	S.O. 9062	S.O. 7474	S.O. 7473	S.O. 7472	S.O. 7471	S.O. 7413	S.O. 7411	S.O. 7412	S.O. 7476	S.O. 7477	S.O. 7478	S.O. 7479	S.O. 7480	S.O. 9085	S.O. 9086	S.O. 7198	S.O. 7197
1	Ammodiscus sp.		V		R					V						V				
2	Amphimorphina ignota Cushman & Siegfus			V	R			R	V	V		R			V					
3	Amphistegina simiensis (Cushman & McMasters)					V														
4	Anomalina dorri Cole var. aragonensis Nuttall	V		V	R		V				V	V	V		V	V	R	V		V
5	Anomalina garzaensis Cushman & Siegfus	V								V					V	V	V	V		
6	Asterigerina crassaformis Cushman & Siegfus	V	V	V	R		V			R			V	R		V				R
7	Bathysiphon eocenicus Cushman & Hanna				V	R	R	R	V					V						
8	Bifarina nuttalli Cushman & Siegfus	V							V											
9	Bulimina corrugata Cushman & Siegfus							V												
10	Bulimina excavata Cushman & Parker					V	R								V	R				
11	Bulimina cf. B. guayabalensis Cole								V											
12	Bulimina lirata Cushman & Parker				V															
13	Bulimina macilenta Cushman & Parker			R																
14	Bulimina semicostata Nuttall															R				V
15	Bulimina serratospina Finlay					V	V			V										V
16	Buliminella grata Parker & Bermudez																			V
17	Cibicides fortunatus Martin							V					V	V		V		V		
18	Cibicides martinezensis Cushman & Barksdale						V													
19	Cibicides mauricensis Howe & Roberts					V													V	R
20	Cibicides perlucida Nuttall	R		C		V									R	V	R	C		
21	Cibicides pseudoungerianus (Cushman)								V											
22	Cibicides pseudoungerianus (Cushman) var. lisbonensis Bandy							R		V			V							
23	Clavulinoides sp.								R		R	R	V				V		V	V
24	Cyclammina pacifica Beck												R							
25	Cyclammina samanica Berry																		V	
26	Dentalina communis (d'Orbigny)					V				V										
27	Dentalina sp.	V				R		V	V						V					
28	Dorothia principiensis Cushman & Bermudez	V		V		V		V			V		V							
29	Eponides patelliformis Stadnichenko				V										V					
30	Eponides umbonata (Reuss)					V			V							V				
31	Globigerina bulloides d'Orbigny			A	R			A	C	C	C	R	R		R	R	C	C		
32	Globigerina triloculinoides Plummer	C		R	C	R	R	R		R		R		R	C	C	R	R	V	V
33	Globorotalia aragonensis Nuttall	C	V	C	R	V		C	C	C	A	C	C	R	C	C	C	R	R	R
34	Glomospira charoides (Jones & Parker)				V															
35	Gyroidina nitida (Reuss)						V													
36	Gyroidina soldanii d'Orbigny						V													
37	Marginulina sp.			V						V	V							V		
38	Marssonella oxycona (Reuss)																	V		
39	Martinottiella cf. M. petrosa (Cushman & Bermudez)	R																		
40	Nodosarella advena Cushman & Siegfus										V									
41	Nodosaria latejugata Guembel					V	R					V	V			V				
42	Nonion applini Howe & Wallace										V									
43	Nonion micrum Cole			V				R			V									
44	Parrella tenuicarinata (Cushman & Siegfus)	V		V				R		R	V	V			V					
45	Pleurostomella nuttalli Cushman & Siegfus										V				V					
46	Pseudoglandulina sp.			V																
47	Pullenia eocenica Cushman & Siegfus									V										
48	Pullenia quinqueloba (Reuss)	V		V																
49	Robulus inornatus (d'Orbigny)	R		R	R		R			R	V		R	R	R	R	V	V	V	
50	Silicosigmoilina californica Cushman & Church				V	V	V									V				
51	Silicosigmoilina sp.	V	V	V						V										
52	Spiroplectammina mississippiensis (Cushman)			V	V															
53	Textularia adalta Cushman				V									R		V				
54	Textularia aff. T. adalta Cushman		V							V	V									
55	Tritaxilina colei Cushman & Siegfus			V		R	R			V	V	V				R			V	V
56	Trochammina irregularis (d'Orbigny)					V						V								
57	Trochammina aff. T. irregularis (d'Orbigny)									V										
58	Vaginulinopsis asperuliformis (Nuttall)	V			R	V	V													
59	Vaginulinopsis mexicana (Cushman) var. alticostata (Cushman & Barksdale)			V																
60	Vulvulina curta Cushman & Siegfus	V					V	V						V						

A–abundant C–common R–rare V–very rare

FORAMINIFERA FROM CHURCH CREEK FORMATION

Church Creek Area, Monterey County, California

Part I: Strata of Refugian Age

	Standard Oil Co. of California Locality Numbers	S.O. 7416	S.O. 7475	S.O. 7414	S.O. 7470	S.O. 7315
1	Ammodiscus sp.		V	R		
2	Anomalina californiensis Cushman & Hobson				R	R
3	Anomalina glabrata Cushman				R	
4	Bathysiphon eocenicus Cushman & Hanna	V	R	R		
5	Bulimina lirata Cushman & Parker	V				
6	Bulimina ovata d'Orbigny	V	V	R	R	R
7	Bulimina sculptilis Cushman	C	R	R		V
8	Cassidulina galvinensis Cushman & Frizzell				V	
9	Cassidulina globosa Hantken				V	
10	Cassidulina subglobosa Brady		V			
11	Ceratabulimina washburnei Cushman & Schenck					V
12	Chilostomella cylindroides Reuss					V
13	Cibicides elmaensis Rau	R	R	V		
14	Cibicides floridanus Cushman					R
15	Cyclammina pacifica Beck		R	R		
16	Dentalina jacksonensis (Cushman & Applin)			R		
17	Dentalina sp.	R	R			C
18	Eponides duprei Cushman & Schenck			V		
19	Globobulimina pacifica Cushman	V				
20	Guttulina hantkeni Cushman & Ozawa				V	
21	Gyroidina condoni (Cushman & Schenck)				R	C
22	Gyroidina orbicularis d'Orbigny var. planata Cushman	R	R	R		
23	Gyroidina planulata Cushman & Renz	R		R		
24	Gyroidina soldanii d'Orbigny				R	R
25	Haplophragmoides trullissata (Brady)	R	R	R	R	C
26	Karreriella washingtonensis Rau			V		
27	Lagena acuticostata Reuss				R	V
28	Nodosaria grandis Reuss				R	V
29	Nodosaria longiscata d'Orbigny	R				
30	Plectofrondicularia packardi Cushman & Schenck		V	V	R	R
31	Plectofrondicularia packardi Cushman & Schenck var. multilineata Cushman & Simonson	V			V	V
32	Plectofrondicularia searsi Cushman, Stewart, & Stewart		V	R		
33	Plectofrondicularia vaughni Cushman		V		V	
34	Pseudoglandulina inflata (Bornemann)				R	V
35	Pullenia salisburyi Stewart & Stewart				R	
36	Robulus sp.	V	V			V
37	Uvigerina auberiana d'Orbigny				V	V
38	Uvigerina gallowayi Cushman	R	C	V	C	R
39	Uvigerina garzaensis Cushman & Siegfus	V				
40	Uvigerina topilensis Cushman			V		
41	Uvigerinella obesa Cushman var. impolita Cushman & Laiming				V	
42	Valvulineria auricana (d'Orbigny)				V	
43	Valvulineria thomasi Cushman & Simonson	V		V		

Part II: Strata of late Eocene (pre-Refugian) age

	Standard Oil Co. of California Locality Numbers	S.O. 8699	S.O. 9083	S.O. 7199	S.O. 8632	S.O. 8619
1	Asterigerina crassaformis Cushman & Siegfus	V				R
2	Cibicides cushmani Nuttall	V				
3	Cibicides perlucida Nuttall			R		
4	Clavulinoides sp.			V		
5	Ellipsopleurostomella sp.				V	
6	Eponides tenera (Brady)	V				
7	Eponides umbonata (Reuss)					V
8	Globigerina bulloides d'Orbigny				C	
9	Globigerina triloculinoides Plummer			V	V	
10	Globorotalia aragonensis Nuttall		V	R	C	
11	Globorotalia crassata (Cushman)		R			
12	Globorotalia marksi Martin					V
13	Globorotalia nicoli Martin	V				
14	Parrella tenuicarinata (Cushman & Siegfus)				R	
15	Robulus cf. R. inornatus (d'Orbigny)		V	V		
16	Robulus cf. R. pseudocultratus Cole					V
17	Tritaxilina colei Cushman & Siegfus			V		
18	Vulvulina curta Cushman & Siegfus				V	

A–abundant C–common R–rare V–very rare

(*Continued from page 41*)

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MAGNETIC STUDY OF THE ISLAND MOUNTAIN MINE AREA, TRINITY COUNTY, CALIFORNIA*

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ABSTRACT

A magnetic study was conducted by the California Division of Mines and Geology at the Island Mountain copper mine in Trinity County. The study consisted of the measurement of the magnetic susceptibilities of a set of rock samples, a number of reconnaissance magnetometer lines, and a detailed magnetometer survey in the vicinity of the mine.

The ore deposit at the mine is a massive sulfide metasomatic replacement consisting principally of pyrrhotite, pyrite, and chalcopyrite in a shear zone in shale and graywacke. The detailed survey revealed a distinct anomaly over the general position of the known ore body and another anomaly to the northwest in an unexplored area. In addition, moderately large anomalies were found over outcrops of andesite on two of the reconnaissance lines. Magnetic susceptibility measurements indicate that the sulfide ore and the andesite are the only known rock types in the area likely to produce significant magnetic anomalies.

An analysis of the magnetic anomaly in the unexplored area suggests an ore zone at shallow depth containing a possible 75,000 tons of ore for each 100 feet of depth extent. It is estimated that there are approximately 218,000 tons of ore within about 150 feet of the surface at the property, including the unmined ore in the known ore body.

INTRODUCTION

A magnetic study was conducted by the California Division of Mines and Geology in the Island Mountain mine area in Trinity County, California, during November, 1961, May, 1962, and July, 1963. The purpose of the study was to investigate the applicability of the magnetic geophysical method in the search for pyrrhotite-copper ore in California. The results of an earlier preliminary survey at the Island Mountain mine, discussed in a report by Stinson (1957, p. 31), suggested that the pyrrhotite mineralization could be successfully detected by magnetic means.

The Island Mountain mine is located on the Eel River in sections 9, 10, and 15, T. 5 S., R. 6 E., Humboldt base and Meridian, about 30 miles east of Garberville and 90 miles north of Ukiah by road. The copper deposit at the mine is one of the largest sulfide deposits known in rocks of the Franciscan Formation and the mine has been the only important producer of copper in Trinity County. In 1915 the property was estimated to contain about 275,000 tons of ore containing recoverable copper, silver, and gold (Averill, 1941, p. 23). The mine property consists of 266 acres of land including four patented mining claims and is owned by Mr. E. R. Leach and associates of Oakland, California.

Access to the Island Mountain mine area from U.S. Highway 101 at Garberville is provided by a dirt county road which becomes impassable during

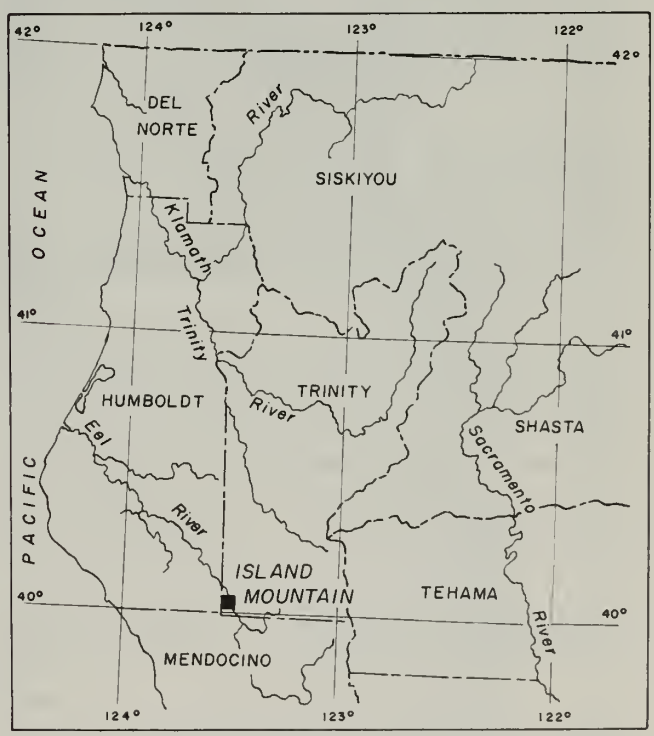


Figure 1. Map showing location of the Island Mountain area.

* Manuscript submitted for publication January 1964.

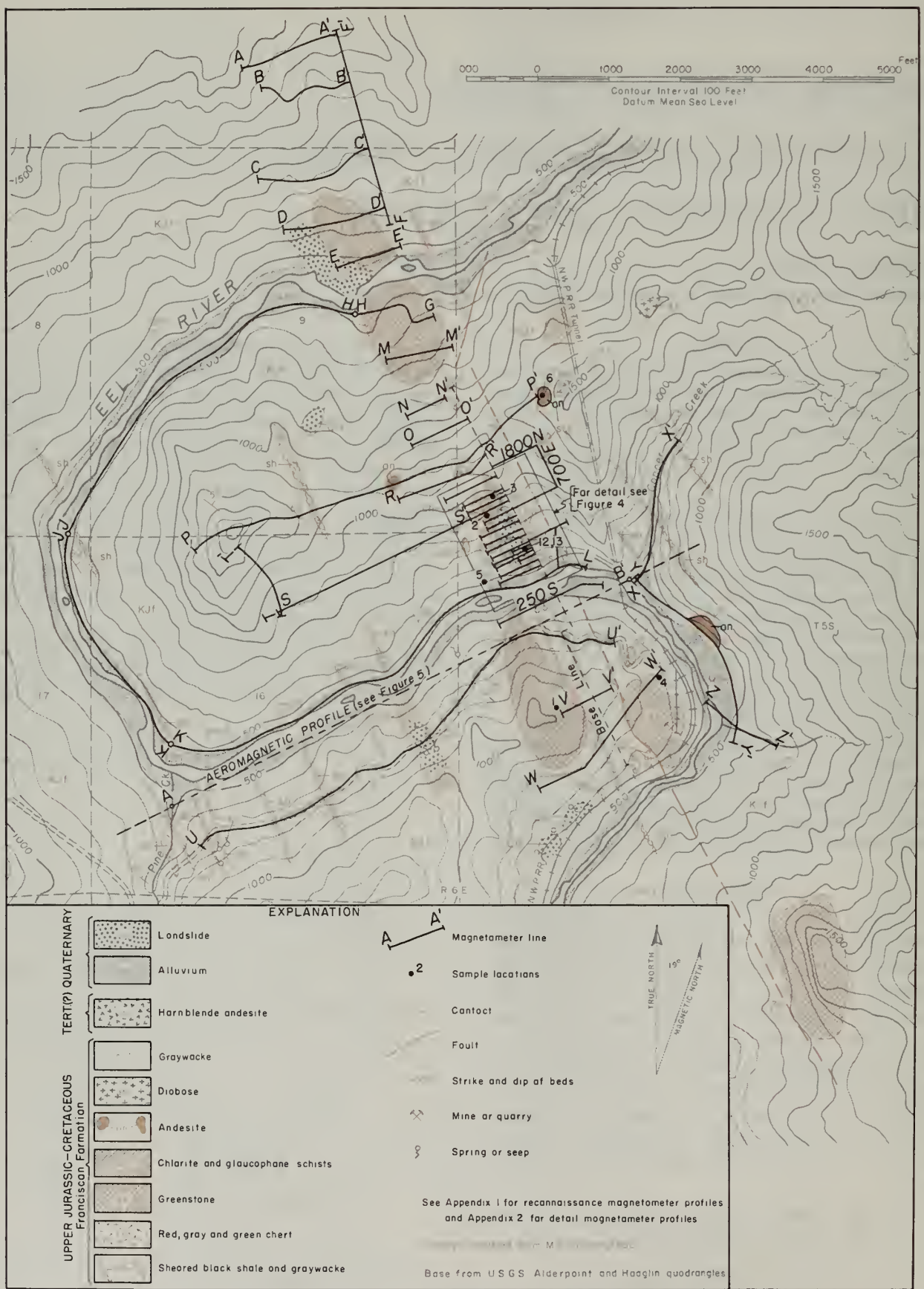


Figure 2. Geologic map of the Island Mountain area, showing location of magnetometer traverses.

wet weather. The Northwestern Pacific railroad line between San Rafael and Eureka crosses the Eel River about 1000 feet east of the mine and passes through a mile-long tunnel in the ridge on which the mine is located. The Island Mountain freight station on the railroad is about 400 yards southeast of the mine, on the opposite side of the river.

The Island Mountain area is in the northern Coast Ranges, a region characterized by fairly rugged relief in the form of northwest-trending ridges and valleys. Elevations range from about 500 feet at the river to over 4,000 feet on the ridge east of Island Mountain station. Landslides are very common in the area; an active landslide at the mine has buried a large portion of the old workings.

Parts of the area are covered with trees and brush, particularly on the northern slopes. The summer months are dry and warm, but rainfall is fairly heavy during the winter. The Eel River is often flooded during the winter and spring months, at which times access to the mine must be on foot or by boat, and is difficult.

The writer wishes to express his appreciation to Mr. E. R. Leach for making available unpublished reports and other information on the mine, and to the Northwestern Pacific Railroad for the use of the company facilities at Island Mountain. C. W. Chesterman and M. C. Stinson suggested the project and offered many valuable suggestions. Charles C. Bishop assisted with both the field work and the compilation of the data.

GEOLOGY

The regional geology of the northern Coast Ranges has been described by Irwin (1960), and that in the vicinity of Island Mountain by Stinson (1957, pp. 12–17). The geologic map, figure 2, has been adapted from Stinson (1957, plate 1) and shows the following rock units: graywacke, black shale, chert, glaucophane schist, greenstone, diabase, andesite, hornblende andesite, landslide material, and alluvium. With the exceptions of alluvium, landslide material, and the hornblende andesite, all of the rocks in the area are tentatively assigned to the Franciscan Formation of probable Late Jurassic or Cretaceous age.

The most common rock type in the Island Mountain area is well-bedded graywacke. Typical graywacke is gray to greenish in color on both fresh and weathered surfaces, and is composed principally of quartz and plagioclase. It commonly contains numerous fragments of black shale. Graywacke forms many of the prominent ridges in the area.

Black shale occurs as thin beds, or lenses, which are enclosed by graywacke; they range in thickness up to about 100 feet. Many of the shale beds show evidence of fracturing and shearing and they probably serve to localize structural movements because of their low strength. Many of the landslide zones are probably caused by the presence of black shale beds.

Lenses of red and brown chert and some large masses of glaucophane schist also occur in the graywacke. At several places glaucophane schist forms distinctive outcrops, such as those on the ridges southwest of Island Mountain station. A prominent outcrop of brown chert and glaucophane schist overlooks the mine workings.

A number of prominent, isolated outcrops of greenstone are present; these masses, which range in size up to 1000 by 2000 feet or more, may have originated as intrusive plugs or dikes. The greenstone is a very dense, green rock characteristically containing many veins of calcite and quartz.

A small body of diabase, about 300 by 600 feet in outcrop, was mapped by Stinson (1957, p. 15) about a third of a mile southeast of the north end of the railroad tunnel; this rock type has not been mapped elsewhere in the area.

Several small outcrops of altered andesite which appear to be intrusive are located on the slopes north of the mine workings, and one is to be found on the east side of the Eel River, east of Island Mountain station. The exposures of this rock on the slope above the railroad tunnel and east of Island Mountain station show an amygdaloidal texture and are less altered than the others. Small pieces of the amygdaloidal andesite can be attracted by a magnet.

A small outcrop of relatively fresh porphyritic hornblende andesite, about 100 by 300 feet in area, is near the top of the hill over the railroad tunnel. Stinson (1957, p. 16) has proposed a Tertiary age for this rock because of structural relationships and the lack of alteration.

Landslide debris is very common. A large landslide is reported to have occurred in the mine area in 1937. This slide was probably caused, in part, by earlier removal of underground material, although it is likely that landslides have occurred periodically here prior to the mining activity. Slides sometimes cover parts of the railroad tracks and roads, particularly during the winter months.

The alluvium shown on Figure 2 is confined to the immediate vicinity of the Eel River and consists of sand and gravel deposited during periods of high water.

The structure of the Island Mountain area is thought to be a simple homocline of rocks of the Franciscan Formation. The strike of the beds is N

25°–30° W; they dip an average of about 70 degrees northeast. Numerous shear zones and faults, marked by landslides and springs, parallel the strike of the rock units. The lenses of chert and glaucophane schist in the graywacke may be remnants of once-continuous beds which have been separated by faulting.

THE ISLAND MOUNTAIN MINE

Mineralization at Island Mountain was first reported sometime before 1897 (Stinson 1957, p. 17) and subsequently several attempts were made to explore the ore zone. However, it was not until 1915, the year after completion of the Northwestern Pacific Railroad, that the Island Mountain Consolidated Copper Company began to mine the deposit. Except for the years 1920 and 1921, mining operations were nearly continuous from 1915 through 1930, at which time a drop in the price of copper forced the mine to close. The mine was never put into operation again and subsequent landslides have buried the tunnels and workings. The mine machinery and buildings have mostly disappeared, having either been carried off or covered by landslide debris. During the years of active mining, according to records supplied by E. R. Leach (Stinson 1957, p. 18), about 132,000 tons of ore were shipped to the smelter; this ore averaged 3.296 percent copper, 1.092 ounces of silver, and 0.0651 ounces of gold per ton. The total mine production has been about 9,000,000 pounds of copper, 144,000 ounces of silver, and 8,600 ounces of gold, according to those records.

The ore deposit at Island Mountain is a massive sulfide metasomatic replacement of shale and graywacke in a shear zone. The ore body blocked out before mining operations began was kidney-shaped, with a northwest trend, a steep dip to the east, and a low angle of plunge (Stinson 1957, p. 20). It was approximately 450 feet long, 120 feet wide in the widest portion, and it extended to a depth of about 140 feet. Figure 3 is a southwest-northeast cross section of the ore body after A. C. Lawson (unpublished report, pp. 1–8, 1918).

The ore deposit, as described by Stinson (1957, pp. 25–31), is composed of pyrrhotite, pyrite, chalcopyrite, and minor proportions of arsenopyrite, galena, sphalerite, cubanite, bornite, and magnetite. The gold and silver probably occur in either the pyrite or chalcopyrite. In addition, many supergene copper and iron minerals have been reported from the mine area.

At the present time, an underground examination cannot be made because the workings are caved and covered with landslide debris, but a few remnants of the unmined ore are exposed (see figure 4). Since

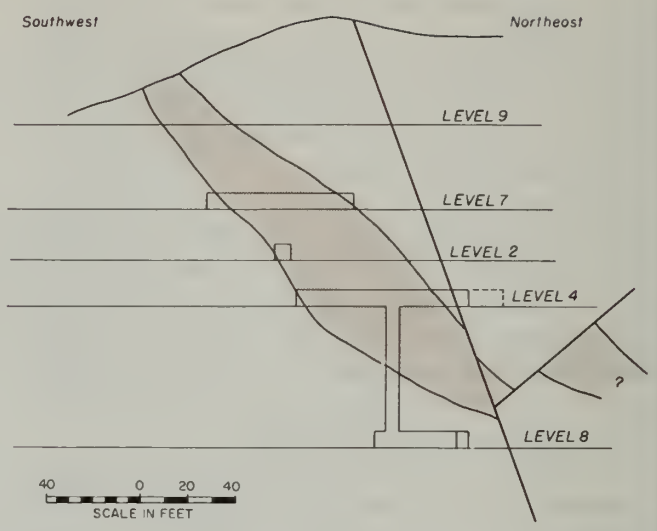


Figure 3. Southwest-northeast crass sectian thraugh the Island Mountain are depasit; lacatian uncertain (after A. C. Lawsan, 1918).

only about 132,000 tons of ore were mined and the ore body was estimated to contain 275,000 tons before mining (Leach, 1911, p. 2), about 143,000 tons of the ore should still be in the ground, if the original estimate was correct.

The known ore body at Island Mountain has a short vertical extent relative to its horizontal length; the ratio of thickness to length is less than 0.3. Because many shear zone deposits have relatively large vertical extents, Stinson (1957, p. 33) suggests that there may be additional ore shoots in the Island Mountain shear zone which were not located in the earlier exploration of the deposit.

GEOPHYSICS

Several magnetometer lines were run over the Island Mountain deposit by Gordon D. Bath of the Geophysics Branch of the U. S. Geological Survey in 1954 (Stinson, 1957, p. 31). These lines indicated that the ore, which consists largely of the mineral pyrrhotite, could be detected by a magnetic survey. Three of these earlier traverses indicated a fairly large anomaly northwest of the old mine workings in the vicinity of the chert-glaucophane schist outcrop. This anomaly suggested the presence of a significant amount of pyrrhotite ore in an unexplored area.

A number of aeromagnetic profiles were flown across the northern Coast Ranges, Great Valley, and Klamath Mountains of California by the U. S. Geological Survey in 1954 (Irwin and Bath, 1962). One of these profiles, D-D′, flown in a northeast direction, nearly passed over Island Mountain station (see figure 2). This profile is located approximately parallel to, and between, ground lines 250 South and U-U′ of the

Figure 4. Vertical intensity magnetic map of the Island Mountain mine area showing geology.

present survey. A detailed part of this magnetic profile from Irwin and Bath (figure 25.1, p. B–66) is shown in figure 5. Points A and B on the profile correspond to the same points shown on figure 2.

The aeromagnetic profile is featureless in the immediate vicinity of Island Mountain. However, because the profile was flown with a terrain clearance of about 1000 feet, it is doubtful that any small magnetic anomalies such as might be related to an ore body of the size of the Island Mountain mine would be recorded except under very favorable circumstances. A small, broad anomaly, a few tens of gammas * in amplitude, was recorded about three miles northeast of Island Mountain over a ridge north of Pilot Peak. The cause of this anomaly is not known but the low amplitude and broad distribution suggest a large mass of moderately magnetic rock rather than concentrated mineralization.

The present study, conducted by the Division of Mines and Geology, consisted of the measurement of the magnetic susceptibilities of a set of rock samples and a vertical intensity magnetometer survey which includes a number of reconnaissance lines, and a detailed survey in the vicinity of the mine.

Magnetic Susceptibility Measurements

Magnetic susceptibility measurements were made on 14 specimens of representative ore and country rock collected in the vicinity of the Island Mountain mine (see table 1).† These were made on a Geophysical Specialties Company magnetic susceptibility bridge through the courtesy of Dr. Stanley Ward of the University of California at Berkeley.

Eight specimens of sulfide ore, two of glaucophane schist, and one each of shale, greenstone, graywacke, and amygdaloidal andesite were tested in order to learn which rock types might cause magnetic anomalies in this area. The number of samples tested was insufficient to permit determination of a complete range of magnetic susceptibility values for any of the rock types, but the values do indicate the general order of magnitude of the differences.

With the exception of the sulfide ore and the amygdaloidal andesite, all specimens tested were found to have relatively low values of magnetic susceptibility (less than 0.00005 c.g.s. units). The eight ore samples tested range in value between 0.00014 and 0.00290 c.g.s. units and the average, excluding the one very low value, is 0.00137 c.g.s. units. Some of these samples appeared to consist largely of the mineral pyrrhotite, but the measured values are distinctly less than the figures of 0.028 and 0.00702 c.g.s. units given for pyrrhotite by Jakosky (1950, p. 161) and Eve and Keyes (1954, p. 21), respectively. The sample of amygdaloidal andesite was found to have a value of 0.00390 c.g.s. units, which indicates that this is a strongly magnetic igneous rock. Thus, of the rocks tested, both the sulfide ore and the amygdaloidal andesite are evidently very magnetic relative to all of the associated rocks and might cause distinct magnetic anomalies in the Island Mountain area.

Table 1. Rock Magnetic Susceptibility Measurements, Island Mountain Area

Sample number	Description	Location	Magnetic susceptibility (c.g.s. units)
1.	Gray-blue glaucophane schist	[a]	0.000048
2.	Gray-blue glaucophane schist containing some muscovite and quartz veins	[a]	0.000014
3.	Black shale containing some quartz veinlets	[a]	0.000014
4.	Light green, compact greenstone, probably an altered igneous rock	[a]	0.000034
5.	Greenish-gray medium grained graywacke, composed of grains of quartz, feldspar, and small pieces of shale	[a]	0.000020
6.	Dark green andesite containing amygdules of calcite and quartz	[a]	0.00390
	SULFIDE ORE SAMPLES		
7.	Pyrrhotite, unreplaced shale, and minor pyrite	ore dump	0.00121
8.	Pyrrhotite, pyrite, and unreplaced shale	ore dump	0.00125
9.	Pyrrhotite, unreplaced shale some pyrite and chalcopyrite	ore dump	0.00138
10.	Pyrrhotite, unreplaced shale, and some pyrite	ore dump	0.00173
11.	Pyrrhotite, unreplaced shale, minor chalcopyrite and pyrite	ore dump	0.00137
12.	Pyrrhotite, unreplaced shale, minor chalcopyrite and pyrite	[a]	0.00290
13.	Pyrrhotite, unreplaced shale, chalcopyrite and pyrite	[a]	0.00184
14.	Shale containing pyrite and chalcopyrite and minor pyrrhotite	float, below mine area	0.00014

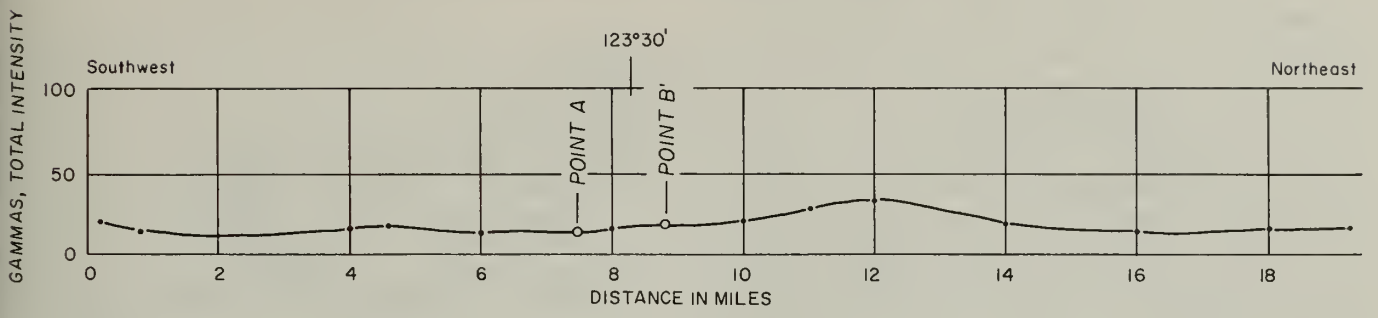
[a] See Figure 2.

Magnetic Survey

A total of over 950 magnetometer observations were made in the area, including both the reconnaissance and detailed lines. A Jalander vertical intensity magnetometer, with a maximum sensitivity of about 10 gammas, was used. The observations were corrected for small diurnal effects by repeated read-

*The gamma, defined as 10^{-5} oersted, is a convenient unit of magnetic field intensity.

† Magnetic susceptibility, given in this report in c.g.s. (centimeter-gram-second) units, is a measure of the ease with which a material may be magnetized in a magnetic field. Magnetic anomalies are caused by rocks or ores which have contrasting magnetic susceptibilities. Magnetite and pyrrhotite are the most common magnetic minerals; in general the magnetite content of common rocks determines their magnetic susceptibilities.



Points A and B' correspond to same points on Figure 2

Figure 5. Aeromagnetic profile, bearing opproximotely N 60° E, over the Island Mountain orea.

ings at a base station; otherwise no adjustments of the data were made.

Reconnaissance Lines

The purpose of the reconnaissance lines was to test the magnetic response of the rock surrounding the Island Mountain mine area and, if possible, to locate any additional magnetic anomalies. The lines were controlled on the ground by Brunton compass and the stations were located by pacing. They were plotted on aerial photographs in the field and later on an enlarged portion of the U.S. Geological Survey Kettenpom and Alderpoint quadrangles. The locations of all magnetometer reconnaissance lines are shown on figure 2 and the magnetic profiles with geologic sections are in Appendix 1.

Because the shear zone in which the Island Mountain deposit occurs may be a structural guide for additional deposits, a number of lines were run over possible projected extensions of this zone both northwest and southeast of the mine area. Many other shear zones in the area were also tested with reconnaissance lines (see figure 2).

Most of the reconnaissance lines show only minor irregular anomalies up to about 100 gammas in amplitude. Line 8, Y-Y′, located on the east bank of the Eel River across from Island Mountain station (see figure 2), shows a distinct, broad anomaly with an amplitude of about 300 gammas over an outcrop of amygdaloidal andesite. The magnetic level on this profile does not return to normal southeast of the andesite outcrop, which suggests that the andesite may be a dike with a low angle of dip to the southeast in the graywacke.

The northeast end of line P-P′ shows a small anomaly near the amygdaloidal andesite outcrop above the railroad tunnel. However, the outcrops of altered andesite crossed by lines P-P′ and R-R′ north of the mine area evidently do not cause anomalies.

Another anomaly with an amplitude of about 200 gammas is found near station 500 South on the base line (see Appendix 1). This anomaly is close to a possible southeast extension of the shear zone at the Island Mountain mine, on the south side of the river, but it is apparently caused by a dump of partially buried metallic objects, rather than mineralization.

Detailed Survey

Detailed magnetometer traverses were made in the Island Mountain mine area from the level of the Eel River to the top of the ridge northwest of the mine, in an area approximately 2,200 feet long by 600 feet wide. Parallel lines, mostly spaced at 50- and 100-foot intervals, were run in a northeast-southwest direction across the trend of the known mineralization.

Stations were located on the lines with a tape; spacing varied from 10 to 100 feet depending on the magnetic gradients and, to some extent, on terrain. Figure 4 is a magnetic anomaly map superimposed on the detailed geologic map of the mine area adapted from Stinson (1957, plate 3). Appendix 2 shows the magnetic profiles with corresponding geologic sections.

An anomaly with an amplitude of about 600 gammas was found in the southeast portion of the area covered by the detailed survey. It has a northwest trend, a length of 600 feet, and it coincides with the approximate position of the old mine workings and known outcrops of ore. This anomaly is designated "Main Anomaly" on figure 4. The presence of some foreign magnetic material such as old rails, cables, and miscellaneous pieces of iron in the landslide debris might have some local effects on the results, but any such effects would probably not cause any significant distortion of the important anomalies. The highest magnetometer readings are over clearly exposed ore, and there is little doubt that the anomaly represents pyrrhotite mineralization.

South of line 400 North the anomaly has a nearly north-south trend and it gradually diminishes in amplitude toward the river. This part of the anomaly could represent mineralization not encountered in

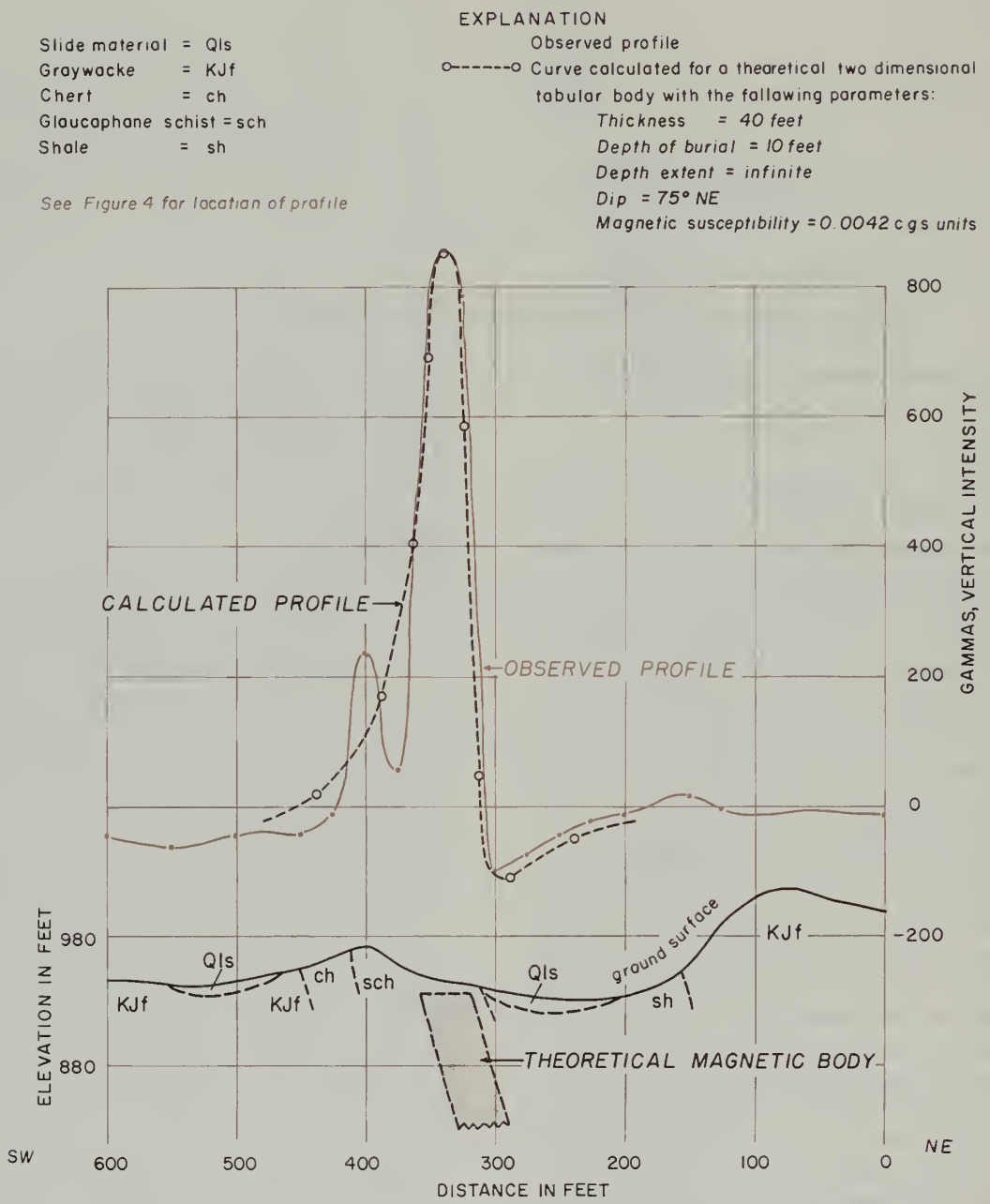


Figure 6. Observed and calculated magnetic anomalies, line 1200 North, Island Mountain mine area.

the old workings, but it could also be caused by an accumulation of float ore. On the north the anomaly divides into two parts, both of which terminate between lines 800 and 900 North.

A second major anomaly is located up the slope, northwest of the old mine workings, between lines 900 and 1300 North. This anomaly was first detected during the 1954 reconnaissance survey (Stinson, 1957, p. 31). The detailed work of the present study indicates that it has a northwest trend, an overall length of about 300 feet, and it consists of two main parts. On figure 4 it is indicated as the "North Anomaly". This anomaly is located just northeast of and in part over a large outcrop of chert and glaucophane schist. The exposed rocks in the area are not significantly magnetic and no mineralization was observed, but the very steep magnetic gradients indicate that the source of the anomaly is very shallow. It is possible that the mass of chert and schist is not in place, but has slid down the hill to its present position thereby covering

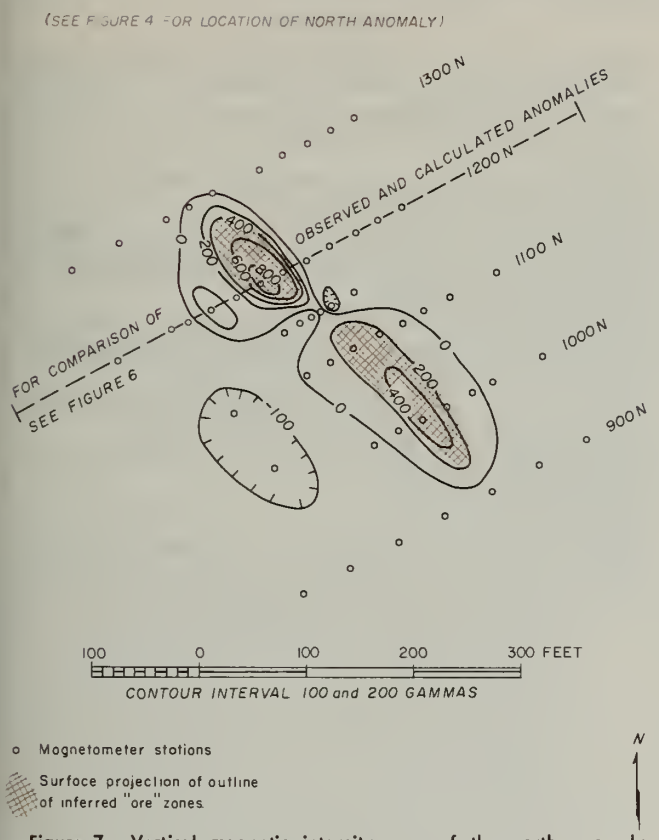


Figure 7. Vertical magnetic intensity map of the north anomaly, showing outline of the inferred "ore" zone.

the source of the anomaly. No exploration is known to have been done in this area.

Because the source of the North anomaly is evidently very close to the surface, the boundaries of the magnetic mass can be estimated closely. It is also possible to calculate the effective magnetic susceptibility contrast, and to make an estimate of the direction of dip and depth extent of the zone. For purposes of a first approximation, the magnetic zone was considered to be two-dimensional (infinite in length). Figure 6 shows a comparison between the vertical intensity anomaly actually observed on line 1200 North and a theoretical anomaly calculated for a tabular magnetic body, following the curve fitting procedure outlined by Cook (1950, p. 686). The parameters of this theoretical magnetic zone are as follows:

Length—"infinite"
Thickness—40 feet
Depth of burial—10 feet
Depth extent—"infinite"
Dip—75° NE
Magnetic susceptibility—0.0042 c.g.s. units

The theoretical magnetic zone has a shallow depth of burial, a steep dip to the northeast, and a depth extent of as much as several hundred feet. The dimensions of this zone, except possibly for the depth extent, and the magnitude and shape of the magnetic anomaly are similar to those of the known ore deposit at the Island Mountain mine. The calculated magnetic susceptibility value of 0.0042 c.g.s. units necessary to explain the anomaly is distinctly greater than the average value of 0.00137 c.g.s. units obtained from measurements of the sulfide ore (see table 1), but it is still a reasonable value for pyrrhotite. It is possible that the few surface ore samples tested are not representative of the bulk of the actual pyrrhotite-bearing ore.

The anomaly could also be caused by some other rock which has a sufficiently high value of magnetic susceptibility, such as amygdaloidal andesite. However, the close proximity of the unknown anomaly to the known deposit at the Island Mountain mine, and the similarity between the anomalies are strong arguments for the cause being additional sulfide mineralization.

Figure 7 is a plan map of the North Anomaly showing the location and outline of the "ore" zone as inferred from the magnetic profiles, assuming that the anomaly is caused by massive sulfides. The near-surface portion of the magnetic zone has an area of about 9,000 square feet. Assuming a factor of 12 cubic feet per ton, a conservative figure, each 100 feet of extent in depth would represent about 75,000 tons of massive pyrrhotite.

The magnetic anomaly does not indicate the copper or precious metal content of the inferred pyrrhotite ore zones. Any new ore may or may not be similar to the ore mined previously. According to the figures presented earlier, approximately 143,000 tons of the ore originally blocked out remain in the ground. This figure has not been verified by underground examination or drilling, but the magnetometer survey tends to corroborate it. Thus, considering both the Main and North Anomalies, there may be a combined total of about 218,000 tons of ore within about 150 feet of the surface and possible additional reserves at depth.

FUTURE EXPLORATION IN THE ISLAND MOUNTAIN AREA

Although the magnetometer survey clearly indicates near-surface mineralization at Island Mountain, it should be noted that magnetic anomalies associated with small ore bodies lose amplitude markedly with increasing depth of burial. Thus, a small pyrrhotite zone with a depth of burial of as little as 100 feet would be difficult to detect. Therefore, although the magnetic survey has confirmed the location of the

partially mined-out ore body and delineated another anomaly which may represent additional near-surface ore, the survey does not give us reliable information on possible ore at relatively great depths. The application of certain deep electrical prospecting methods or drilling would be recommended procedures for additional exploration in the immediate vicinity of the Island Mountain mine.

The reconnaissance magnetometer lines revealed no obvious anomalies which might represent ore, but anomalies could be present in parts of the Island Mountain area not covered by these lines. Detailed ground magnetic and electrical prospecting techniques in areas selected by geochemical surveys might be the most successful exploration method. The airborne magnetometer in either a fixed wing aircraft or a helicopter would be difficult to employ because of the small size of the anomalies and the rugged terrain.

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APPENDIX I

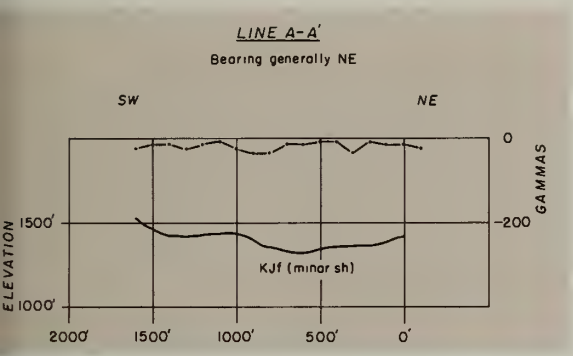
RECONNAISSANCE MAGNETOMETER PROFILES SHOWING GEOLOGIC SECTIONS

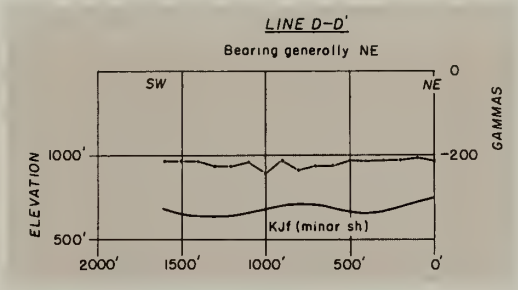
Island Mountain Area, Trinity County, California

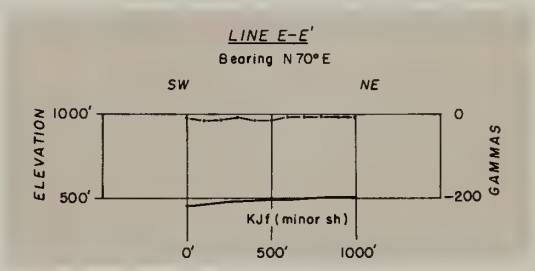
Magnetic profiles by R.H. Chapman and C.C. Bishop, 1961, 1962. Geology modified from M.C. Stinson, 1952.

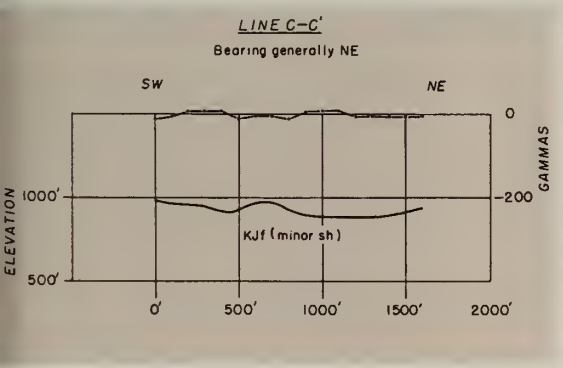
Alluvium [Qal], Landslide [Qls].
Franciscan Formation: [KJf] graywacke, [sh] shale, [an] andesite, [gs] greenstone, [ch] chert, [sch] glaucophane schist.

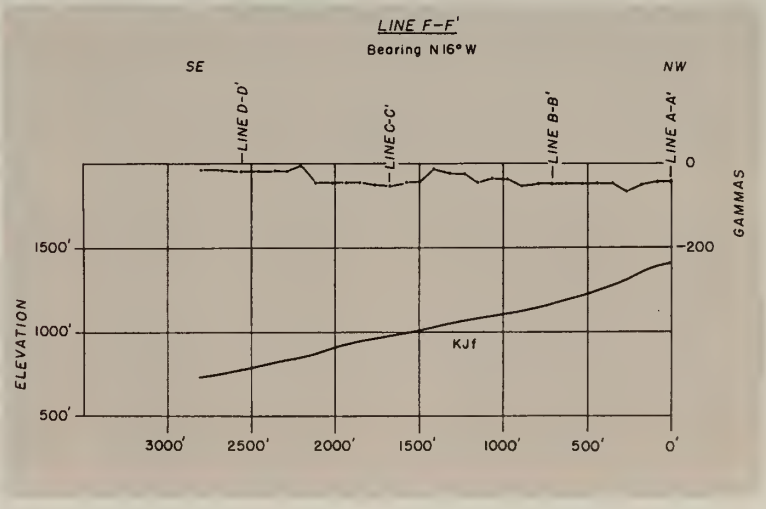
See figure 2 for location of profiles

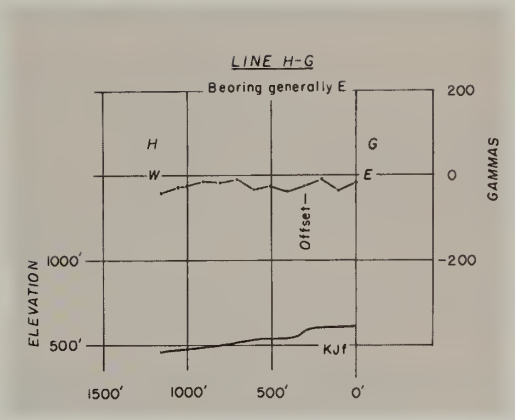








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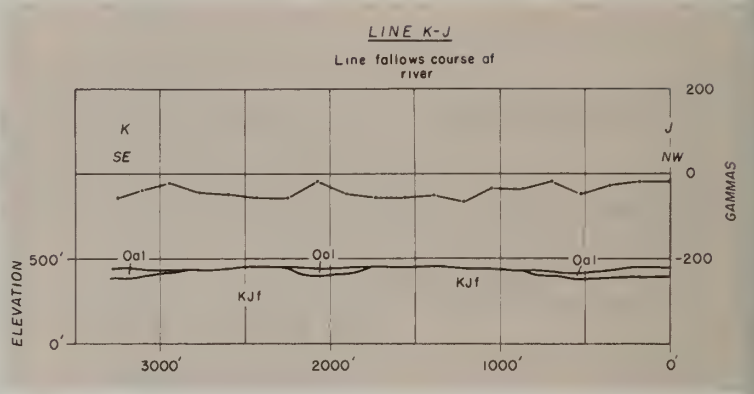
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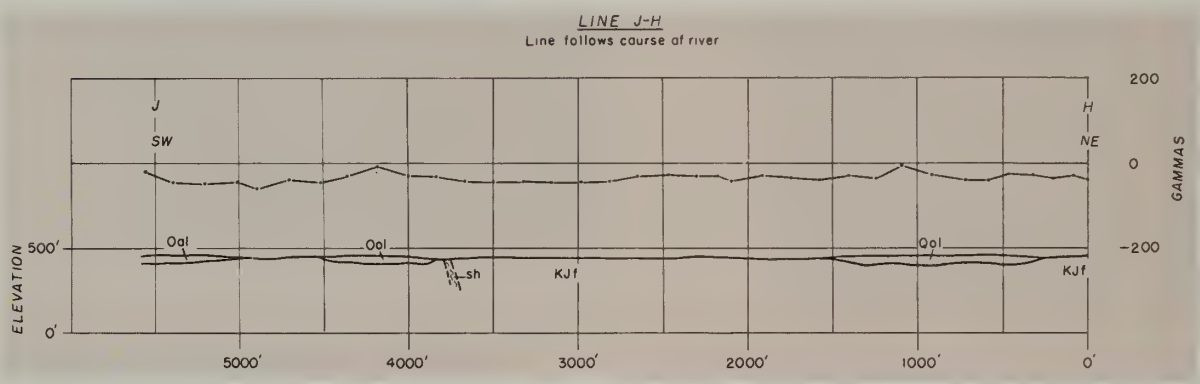
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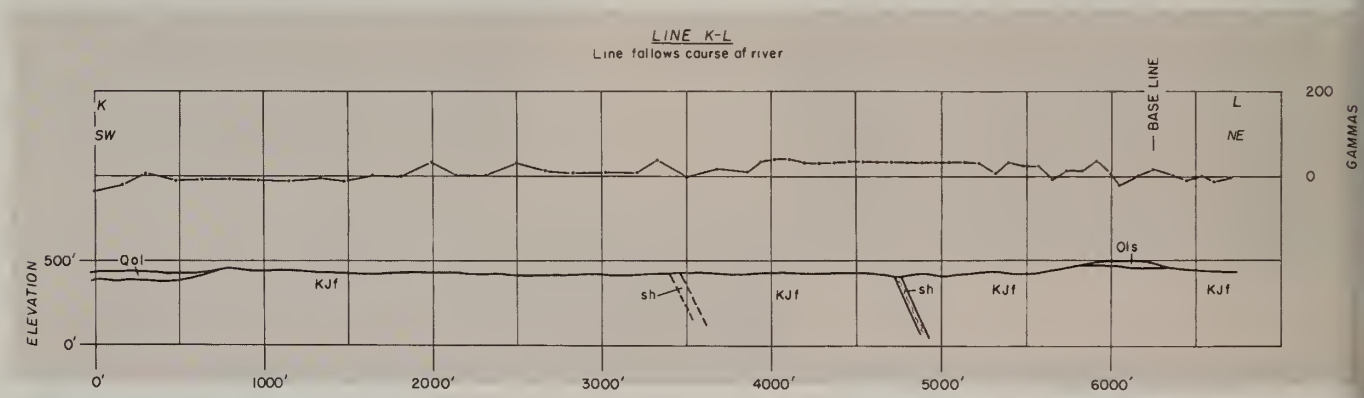
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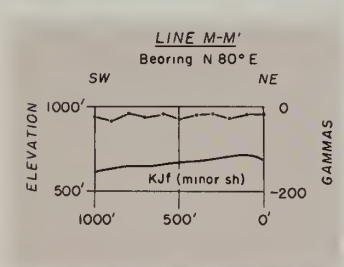
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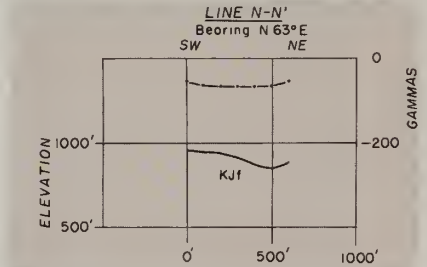
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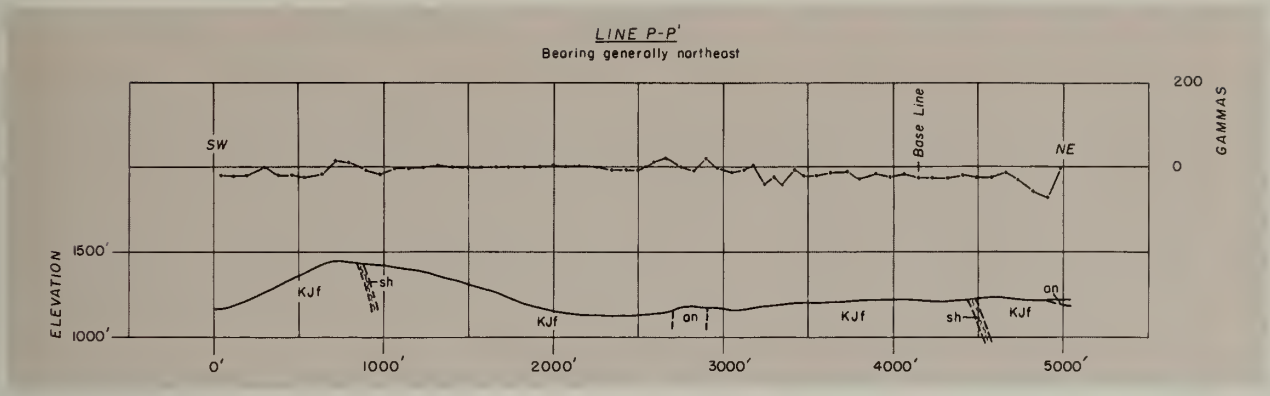
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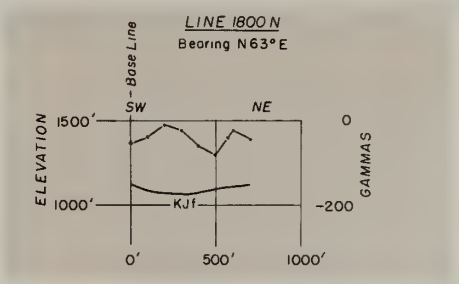
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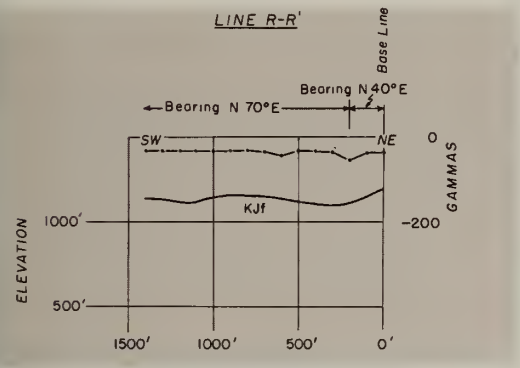
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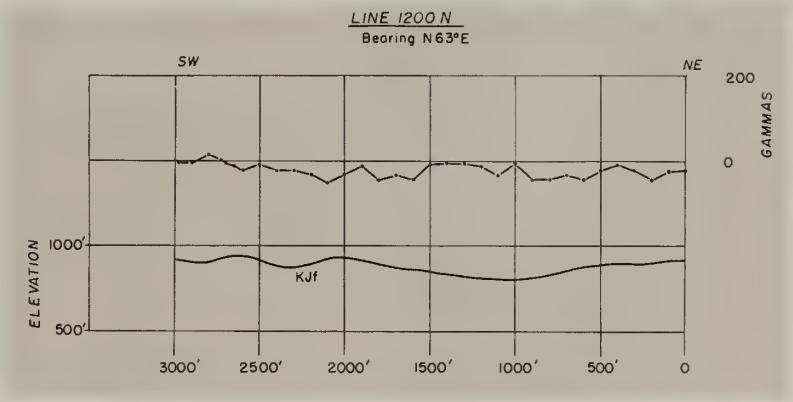
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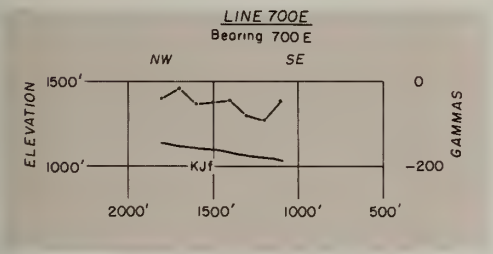
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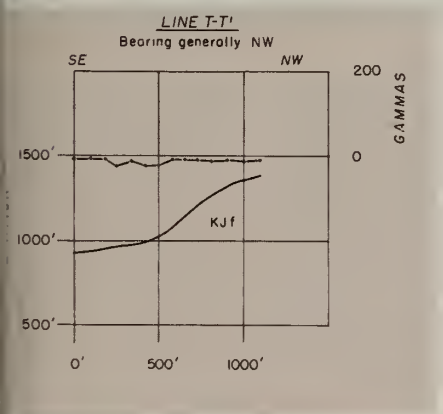
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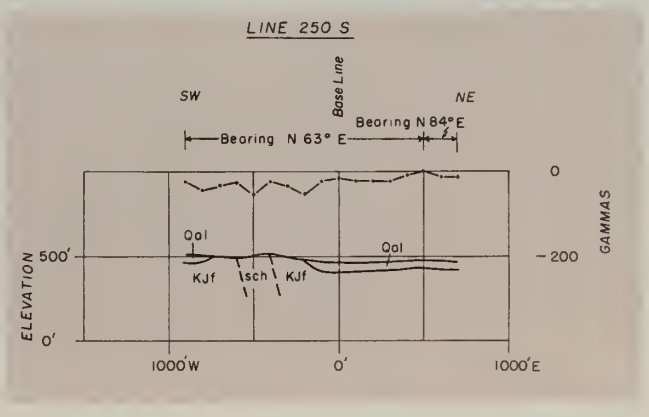
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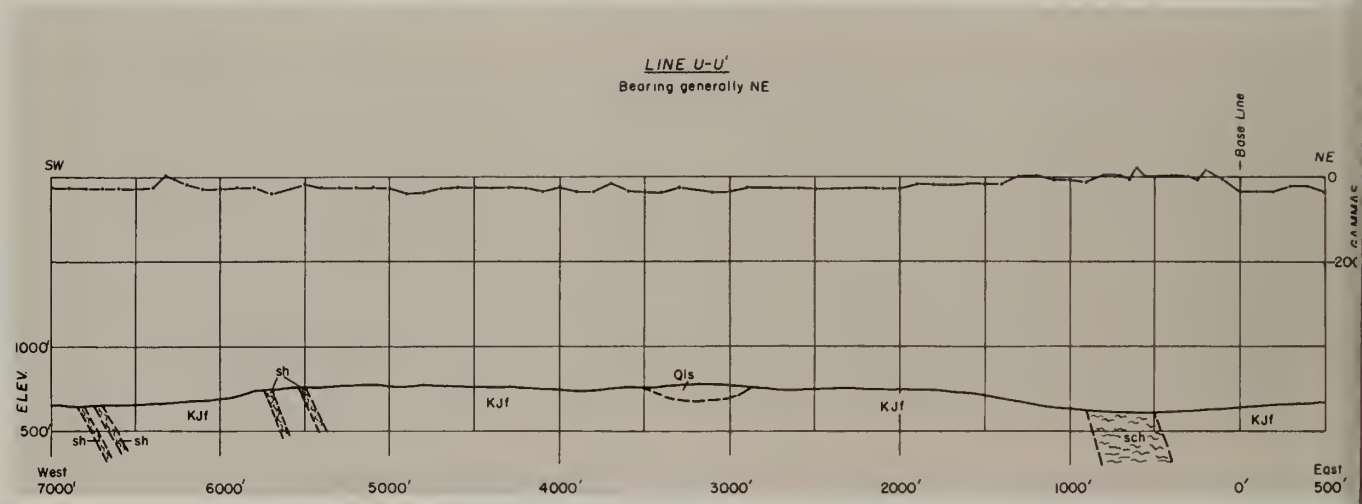
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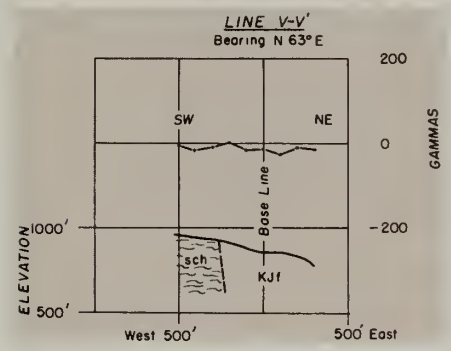
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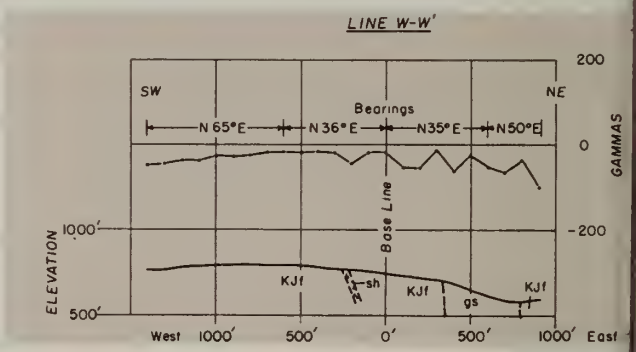
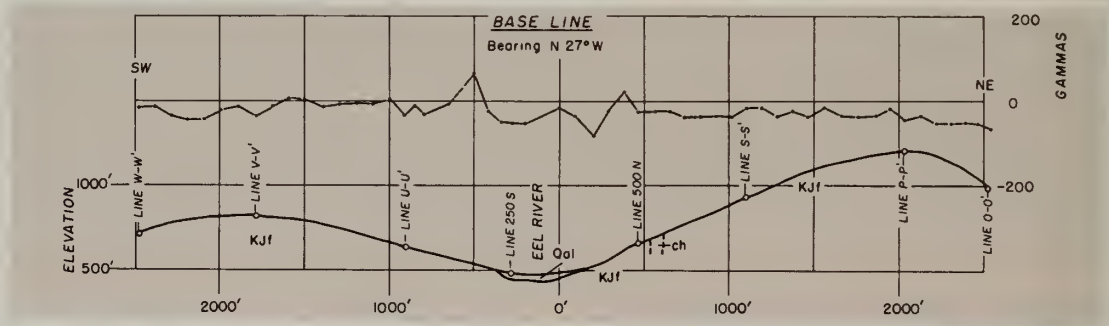
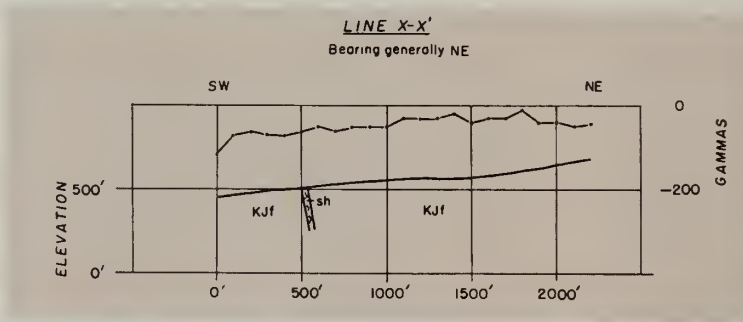
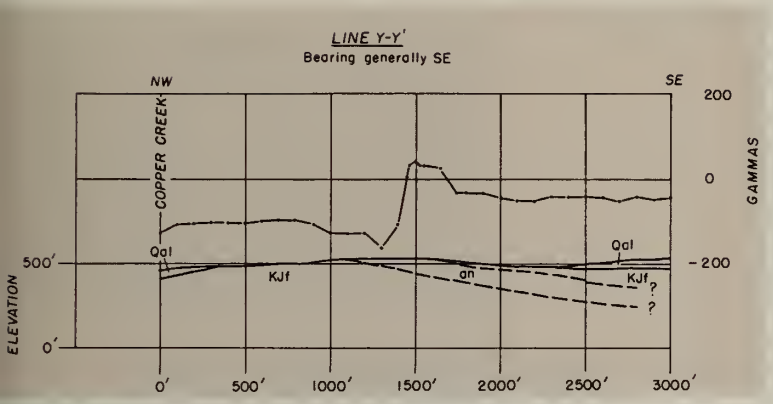
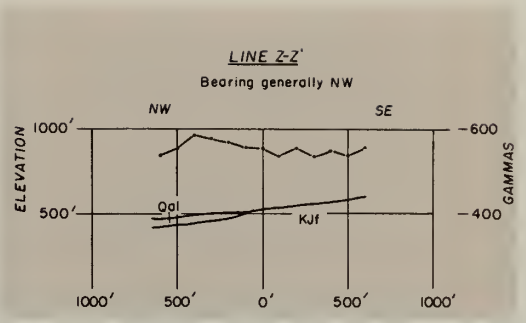
West 500'
500' East


LINE W-W'
SW
NE
Bearings
N 65°E
N 36°E
N35°E
N50°E
200
0
-200
GAMMAS
Base Line
1000'
ELEVATION
500'
KJf
sh
gs
West
1000'
500'
0'
500'
1000'
East


BASE LINE
Bearing N 27°W
SW
NE
200
0
-200
GAMMAS
1000'
ELEVATION
500'
LINE W-W'
LINE V-V'
LINE U-U'
LINE 250 S
EEL RIVER
LINE 500 N
LINE S-S'
LINE P-P'
LINE O-O'
KJf
Qal
ch
2000'
1000'
0'
1000'
2000'


LINE X-X'
Bearing generally NE
SW
NE
0
-200
GAMMAS
500'
ELEVATION
0'
KJf
sh
KJf
0'
500'
1000'
1500'
2000'





END OF APPENDIX I

APPENDIX II

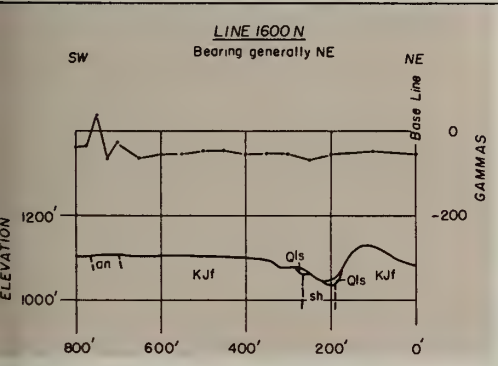
DETAILED MAGNETOMETER PROFILES SHOWING GEOLOGIC SECTIONS

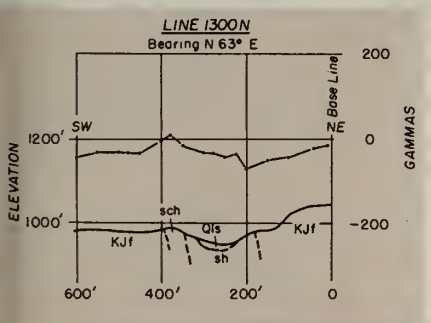
Island Mountain Area, Trinity County, California

Magnetic profiles by R.H. Chapman and C.C. Bishop, 1961, 1962. Geology modified from M.C. Stinson, 1952.

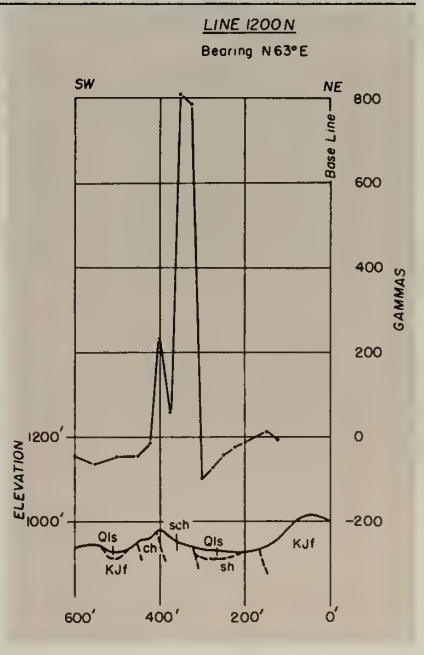
Alluvium [Qal], Landslide [Qls].

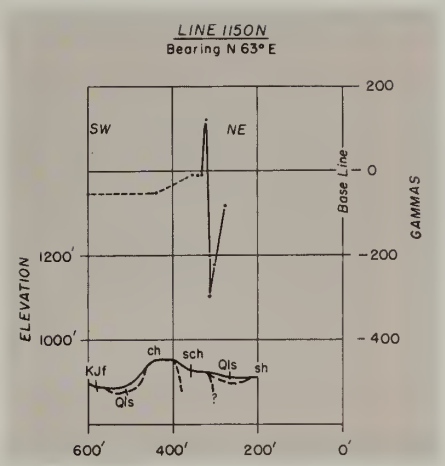
Franciscan Formation: [KJf] graywacke, [sh] shale, [an] andesite, [ch] chert, [sch] glaucophane schist, [ms] massive sulfide.

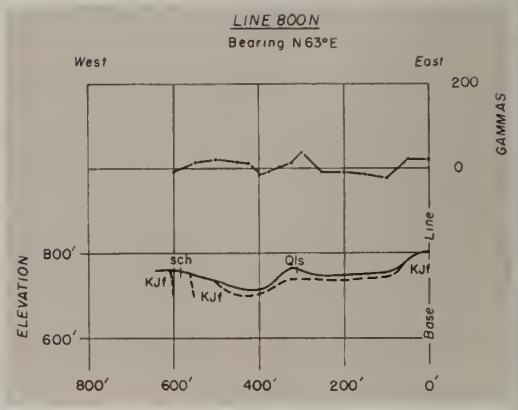


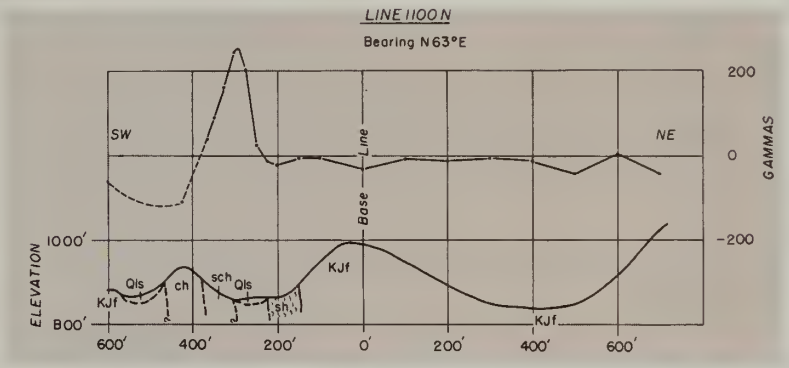


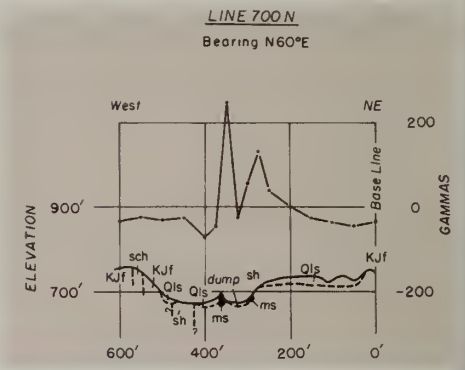
See Figure 4 for location of profiles

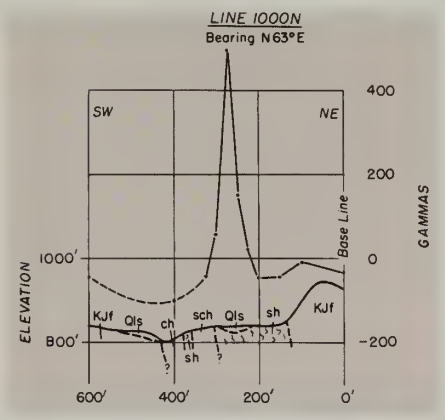


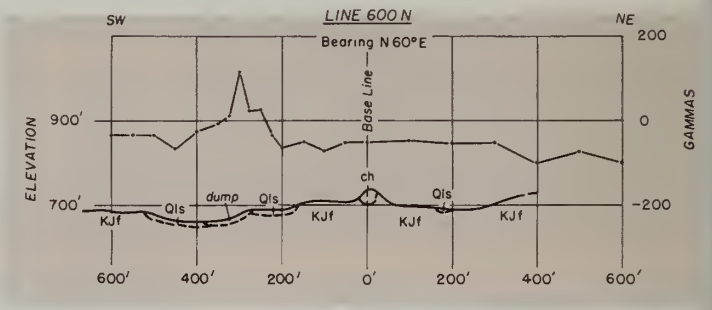

LINE 1150N
Bearing N 63° E
SW
NE
Base Line
GAMMAS
ELEVATION
200
0
-200
-400
1200'
1000'
ch
sch
Qls
sh
KJf
Qls
600'
400'
200'
0'

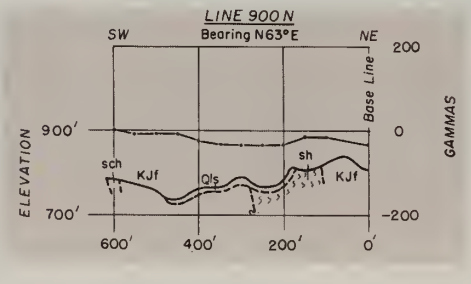

LINE 800N
Bearing N63°E
West
East
GAMMAS
ELEVATION
200
0
800'
600'
sch
Qls
KJf
KJf
KJf
Base Line
800'
600'
400'
200'
0'

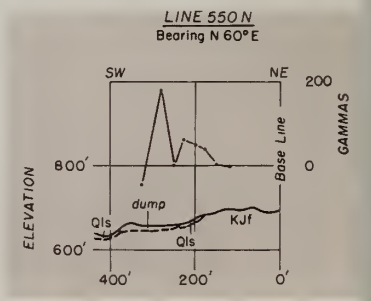

LINE 1100N
Bearing N63°E
SW
NE
Base Line
GAMMAS
ELEVATION
200
0
-200
1000'
800'
Qls
ch
sch
Qls
KJf
sh
KJf
KJf
600'
400'
200'
0'
200'
400'
600'

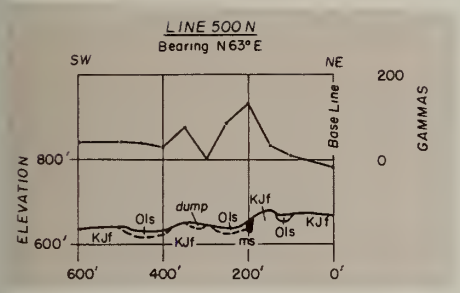

LINE 700N
Bearing N60°E
West
NE
GAMMAS
ELEVATION
200
0
-200
900'
700'
sch
KJf
KJf
Qls
Qls
dump
sh
Qls
KJf
sh
ms
ms
Base Line
600'
400'
200'
0'

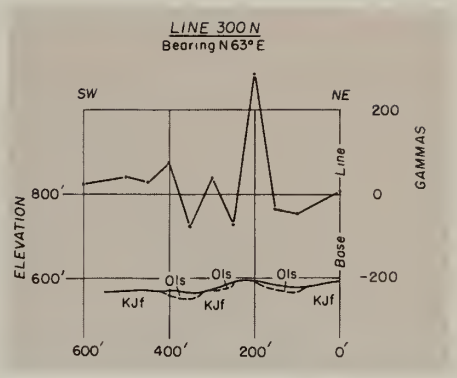

LINE 1000N
Bearing N63°E
SW
NE
Base Line
GAMMAS
ELEVATION
400
200
0
-200
1000'
800'
KJf
Qls
ch
sch
Qls
sh
KJf
sh
600'
400'
200'
0'

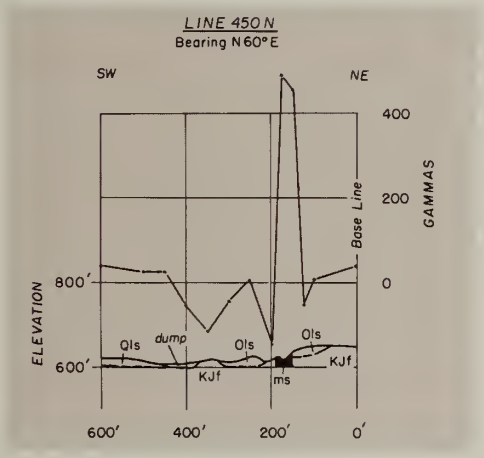

LINE 600N
Bearing N60°E
SW
NE
Base Line
GAMMAS
ELEVATION
200
0
-200
900'
700'
Qls
dump
Qls
ch
Qls
KJf
KJf
KJf
KJf
600'
400'
200'
0'
200'
400'
600'

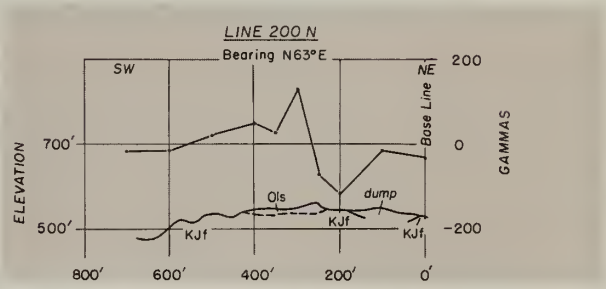

LINE 900N
Bearing N63°E
SW
NE
Base Line
GAMMAS
ELEVATION
200
0
-200
900'
700'
sch
KJf
Qls
sh
KJf
600'
400'
200'
0'

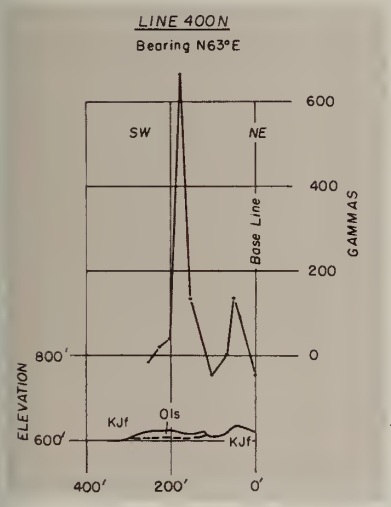

LINE 550N
Bearing N 60°E
SW
NE
Base Line
GAMMAS
ELEVATION
200
0
800'
600'
dump
KJf
Qls
Qls
400'
200'
0'

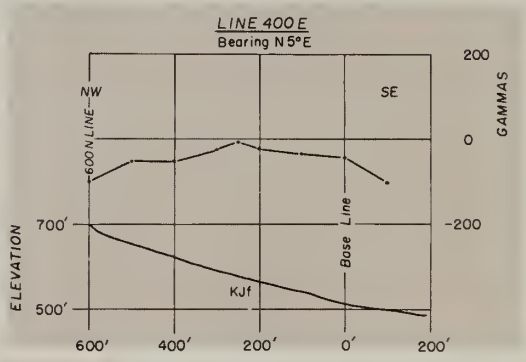


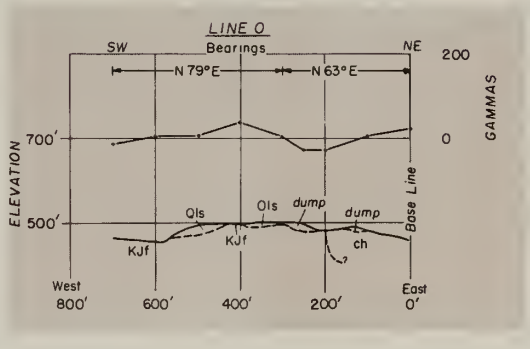












END OF APPENDIX II

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